European Journal of Personality, *Eur. J. Pers.* **26**: 414–431 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1866

Dimensions of Normal Personality as Networks in Search of Equilibrium: You Can't Like Parties if You Don't Like People

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Abstract: In one currently dominant view on personality, personality dimensions (e.g. extraversion) are causes of human behaviour, and personality inventory items (e.g. 'I like to go to parties' and 'I like people') are measurements of these dimensions. In this view, responses to extraversion items correlate because they measure the same latent dimension. In this paper, we challenge this way of thinking and offer an alternative perspective on personality as a system of connected affective, cognitive and behavioural components. We hypothesize that these components do not hang together because they measure the same underlying dimension; they do so because they depend on one another directly for causal, homeostatic or logical reasons (e.g. if one does not like people and it is harder to enjoy parties). From this 'network perspective', personality dimensions emerge out of the connectivity structure that exists between the various components of personality. After outlining the network theory, we illustrate how it applies to personality research in four domains: (i) the overall organization of personality components; (ii) the distinction between state and trait; (iii) the genetic architecture of personality; and (iv) the relation between personality and psychopathology. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: normal personality; networks; latent variable models; personality traits

People differ widely in how they navigate through the landscape of life: some people feel comfortable around others and like to go to parties, whereas others do not. Some worry much and often have trouble sleeping, whereas others rarely experience such problems. Two main challenges in personality psychology are (i) to provide a plausible account of how the coherent 'organization' of such behaviours arises within an individual and (ii) to describe and explain the structure of 'individual differences' in personality (Caprara & Cervone, 2000). Modern personality psychology has mainly focused on the latter task. Starting with pioneering work of, among others, Thurstone (1934), the dominant doctrines in current personality theory have come to define individual differences in the structure of personality in terms of a number of unobserved trait 'dimensions' (e.g. neuroticism and extraversion; Berrios, 1993; Digman, 1990; Goldberg, 1993).

In most interpretations of this concept, consistent differences between people in the behaviour they display are thought to result from underlying differences in these personality dimensions. The interpretation of the term 'underlying' is typically borrowed from measurement models in psychometrics, which invoke latent variables—variables that are indirectly measured through a number of noisy indicator variables (i.e. personality inventory items; Borsboom, 2008a). In line with this mode of thinking, the items of a personality inventory are usually considered to be 'trait measurements', for example, the item 'I like to go to parties' is considered a measurement of the dimension/trait extraversion. Analogous to temperature, which causes mercury to rise and fall in a mercury thermometer, personality dimensions are presumed to cause responses to personality questionnaire items. That is, higher levels of extraversion cause people to make friends more easily and to feel good in the company of others, and these properties are queried in typical questionnaire items. Thus, for example, Alice is not only more extraverted than Bob in the sense that her responses can be 'described' by a higher position on an abstract personality dimension (i.e. extraversion); her higher level of extraversion is what 'causes' her to like parties better than Bob does. In this way, personality dimensions are interpreted as causes of human behaviour. Perhaps the most outright commitment to this point

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of view is expressed in McCrae and Costa (2008, pp. 288) who claim that 'E[xtraversion] causes party-going'.

In the present paper, we challenge this approach to personality. In addition, we offer an alternative perspective. We propose that personality is a system of inter-connected affective, cognitive and behavioural 'components'. More specifically, we propose that every feeling, thought or act is a potential component of personality if it is associated with a unique 'causal system': the pattern of causes and effects that the component exhibits in relation to other components. The component thus must be unique in the sense that its causal system differs from that of other (potential) components. This means that a personality component is, to a certain degree, causally autonomous and, as such, not 'exchangeable' with other components. Thus, liking parties is a personality component because it has unique causes and effects on other components (e.g. being interested in meeting new people and not feeling insecure about making a good first impression) that differ from the causes and effects of other components (e.g. starting conversations easily, also an extraversion item, does not necessarily imply that one is interested in meeting new people). To the contrary, making to-do lists that are followed point by point and sorting clothes by colour may not be separate components at the level of personality (i.e. their causes and effects on other components will likely be similar) but two ways of assessing one component, namely liking order. Barring such exceptions, personality components are typically assessed through single items in personality inventories.[1] This is because two items that assess precisely the same component will be very highly correlated, which tends to cause problems in typical psychometric analyses (i.e. this will show up as correlated errors).

We hypothesize that such components cannot change independently of one another and, therefore, form a network of mutual dependencies that may alternatively have causal, homeostatic or logical sources. Directional dependencies (typically associated with 'causality') will form if one component influences the other but not the other way around: for example, if one cannot plan ahead, it is difficult to meet obligations at work. Bidirectional dependencies will form if two components influence one another (and, as such, create a feedback loop): for example, after a sleepless night worrying, one may feel stressed out and tired the next day; as a result of which, one may not sleep the following night either because of worries about yet another sleepless night. An important special case of feedback involves negative feedback loops that serve to maintain 'homeostasis': for instance, after a few sleepless nights, one will ordinarily get so tired that one will start sleeping again (incidentally, if this does not happen, problems are likely to spread to other components, e.g. not being able to concentrate and foul mood; Cramer et al., 2010). Finally, semantically 'logical' dependencies will form if two components assess the same or a narrower/broader version of a personality characteristic (which may ultimately but not necessarily result in these two components being merged into one component): for example, liking a clean house and liking a clean desk. We postulate that the resulting pattern of connectivity among such components provides a fruitful avenue into personality research. Also, the dependencies between these components result in a typical network architecture (e.g. being interested in other people and spending time with them are mutually dependent while planning ahead and liking people are not) that can serve as a sufficient explanation of the correlational structures typically observed in personality research (e.g. trouble falling asleep and feeling jittery are more strongly correlated than feeling jittery and liking people).

This opens the perspective of a personality theory that is holistic (i.e. that is about the 'organization' of behaviour: network architecture) and that addresses personality at the level of the individual but is nevertheless systematically formalizable through network models. Importantly, this view does not regard personality dimensions as causes of behaviour. We will instead argue that personality dimensions emerge out of the connectivity structure that exists between its components, such that certain components cluster together more than others, with the known personality dimensions as a result.

The structure of this paper is as follows. First, we examine affective, cognitive and behavioural components of personality and argue that a network perspective naturally accommodates mutual (in)dependencies among them (see also Cramer et al., 2010; Schmittmann et al., in press; cf. Read et al., 2010, for similar perspectives). We describe the consequences of the network perspective for prominent topics in personality psychology in the subsequent sections of the paper, which deal with the state–trait distinction, the relation of personality to psychopathology and the genetic basis of personality. Throughout the paper, we relate the network perspective to currently dominant trait theories.

HUMANS AS DYNAMICAL SYSTEMS

Few psychologists would challenge the conclusion that human beings are complexly organized. Even the simplest behavioural act (e.g. starting a conversation with a stranger while waiting for the bus) reinforces cognitive schemas (e.g. it provides evidence for the hypothesis that one is capable of starting such a conversation) and affective conditions (if the small talk is successful, this most likely generates a feeling of satisfaction). Because these cognitive and affective components are associated with a class of behaviours in a given situation, they almost certainly serve to sustain the ability and willingness to

[1]We acknowledge that personality inventories tend to measure self-concept, a person's view of one's own personality that might, to some extent, deviate from one's actual, objective personality. Because the network perspective is undecided concerning whether or not personality networks should be solely based on objective personality, or on both objective personality and self-concept, using personality items as a starting point for defining personality components is sensible, also given the lack of viable alternatives. Future experimental research with a focus on elucidating whether thoughts/feelings/acts, and their mental representations, have unique effects on other personality components might prove beneficial in refining personality networks in terms of what components they should contain: objective ones or also their mental representations. However, we note that current latent trait models often do equate self-concept and objective personality: the personality literature shows an abundance of statements concerning traits (e.g. women are more neurotic compared with men, suggesting an objective difference); the evidence for which is often based on personality inventory items (a more appropriate statement would then be as follows: women's self-concept of their personalities tends to include more neurotic features compared with men).

DOI: 10.1002/per

execute these behaviours when a similar situation is encountered in the future (Mischel & Shoda, 1995). That is, one who has successfully engaged in small talk and enjoyed it is likely to engage in small talk again.

Thus, even this extremely simple example suggests the presence of feedback loops among the components of the personality system, in which behaviour is not just an outcome variable in need of explanation but itself may serve as input to the system (i.e. the behaviour was successful so probably will be executed again under similar circumstances in the future). There most likely are many such feedback mechanisms operating at different time scales, giving rise to a dauntingly complex picture. Thus, Skinner (1987) was definitely on target when he said that human behaviour is 'possibly the most difficult subject ever submitted to scientific analysis'. In fact, in view of the stunning complexity of the system, it should be considered remarkable that stable behavioural patterns exist at all.

But they do. For some reason, human systems tend to settle in relatively fixed areas of the enormous behavioural space at their disposal, where they are in relative 'equilibrium' with themselves and their environments. By equilibrium, we mean a stable state (e.g. Joan is interested in other people and sympathizes with their feelings; as a result of which, she has a job as a social worker) that is not left upon a small disturbance (e.g. one of Joan's clients steals some money from her; after which, she is naturally disappointed in the culprit, but she is still interested in people and their feelings, and she continues her job as a social worker). This definition of equilibrium is analogous to 'attractors' in the complex systems literature (e.g. Teschl, 2008).

The idea that human beings strive to survive and reproduce by actively interacting with their environments is an old one and can be traced back to Darwin (1871). In psychology, several scholars have argued for a theory in which human beings are open systems that are constantly searching for equilibrium or a state of homeostasis. Such equilibriums have been argued to exist with respect to components internal to the human system (e.g. in Freudian psychology, id and superego) and with respect to the relation between the human system and its environment (Allport, 1960; Stagner, 1951; Tryon, 1935).

Such states of homeostasis, which we designate to be 'behavioural equilibriums', can be achieved and maintained in several ways. For instance, people can and will (consciously or not) seek out environments that match their behavioural repertoire (e.g. Heady & Wearing, 1989; Kendler & Baker, 2007; Kendler, Gardner & Prescott, 2003). For instance, Alice, who loves to go to parties, actively seeks environments that provide many opportunities to party and to meet people who can invite her to parties. Thus, organism–environment feedback loops are important sources of stability because they can serve to sustain behavioural patterns. As a consequence of such feedback-driven selection of environments, however, other behavioural states can also become more difficult to access. This is because they would require different types of environments. For example, Alice cannot both love parties and dislike being around people at the same time. For the former preference to thrive, a socially busy environment with many parties is required, whereas the latter preference would require a more tranquil environment featuring only a limited number of people. Thus, active selection of environments has two important consequences. First, it allows people to settle in a 'typical' pattern of behaviour (a behavioural equilibrium, analogous to an 'attractor' in complex systems theory) through organism–environment feedback loops. Second, it creates negative dependencies between behaviours that require different environments because people's behavioural options are not inexhaustible: every behavioural act comes at the expense of not performing another and, as such, closes the futures that could have been if another act had been chosen.

It is further characteristic of the behavioural patterns typically studied under the rubric of personality that they can be shaped and maintained in a variety of ways. Thus, people can respond in their own idiosyncratic ways to the situations in which they find themselves. For example, Jane does not like being around people she does not know very well, so when an acquaintance throws a party, she will attend but she will not mingle much and go home as early as is politely possible. However, at a family reunion, she enjoys the company of her close relatives and stays late to catch up with them. These idiosyncratic patterns of situationally dependent responses have been addressed in the cognitive–affective personality system, which we consider to be naturally compatible with a network perspective (CAPS; Mischel & Shoda, 1995, 1998). According to the CAPS model, personality depends not only on the person but also on the environment, that is, one's idiosyncratic way of behaving is stable within environments but variable across environments.

As a result, each person defines a somewhat idiosyncratic equilibrium with his or her environment that is likely to be organized around some properties that play key roles in the individual's cognitive and affective economy, that is, that are important to the person (Cervone, 2005). Because of the connectivity structure of the human–environment system, these properties cannot vary entirely in isolation: one is unlikely to enjoy parties if one does not like people, one is less likely to enjoy company if one is nervous around others, and one cannot be nervous around others if company makes one feel comfortable. Similarly, in the realm of conscientiousness, one cannot be completely successful at finishing tasks in time if one cannot plan ahead, and for finishing tasks, it generally helps if a person enjoys working hard. Some of these properties are connected, in the sense that they are mutually dependent on one another. Other properties are unconnected or very weakly connected (i.e. relatively mutually independent). For instance, one can like working hard without being able to make friends easily. Thus, these dependencies between personality components define the structure of the network that characterizes a person, that is, is the personality architecture (Cervone, 2005).

Now, suppose that one settles into a behavioural equilibrium with respect to one property. Say, a person likes to be around people and as a child seeks the company of others systematically (for a similar point of view, see Caspi, Bem & Elder, 1989; Caspi, Elder & Bem, 1987, 1988). As a result, one's social skills are developed and improve over time, which makes it easier to be around others, among others, until at some

DOI: 10.1002/per

point an equilibrium is reached. This means that the situation has become relatively stable: one likes to be around others, and one has succeeded in finding a way to realize that state (e.g. a job in a social environment), barring situations where one is temporarily and involuntary 'kicked out' of equilibrium (e.g. being ill and therefore unable to leave the house for some time). Then, the evolution of this property (i.e. enjoying the company of others) will cause other properties, such as social skills, to co-evolve into a related equilibrium: it is quite hard to like to be around people and actively seek out environments that match this preference without at the same time developing social skills. Another person may reach the same equilibrium but approach it from the other direction; for some reason, the person becomes highly skilled in social interactions and comes to like the company of people as a result. Thus, groups of properties will move synchronously, like a flock of birds or a swarm of bees, simply because the organization of the human system and its environments require it.

This idea stands in stark contrast with the idea that behaviour is caused by a small set of latent personality dimensions/traits. In terms of the flock of birds analogy: in the situation as mentioned earlier, one bird in the flock flies in a particular direction because its neighbouring birds do so; in a latent trait scenario, all birds in the flock fly in a particular direction because of the instructions of an invisible (i.e. latent) bird. That is, in the standard model, personality dimensions/traits function as 'common causes' of a set of item responses (Borsboom, 2008a; Edwards & Bagozzi, 2000; Schmittmann et al., in press). In psychometric terms, one of the most important features of a latent trait model that signals this assumption is 'local independence' (e.g. Holland & Rosenbaum, 1986; Lord, 1953; McDonald, 1981). Local independence means that, conditional on any given position on the latent variable, the observed item responses are statistically independent. Essentially, this means that the associations between items are spurious in the sense that they arise 'solely' from the items' common dependence on the latent variable. This is structurally analogous to the textbook example of the correlation between the number of storks and the number of newborns across Macedonian villages: villages that have more storks also have more newborns. This association is spurious because the correlation between storks and newborns arises solely from both variables' dependence on village size: larger villages have more chimneys, which attracts storks, and more people, who produce babies.

A latent variable model works in the same way. It relies on the assumption that dependencies among the cognitive, affective and behavioural components of personality (i.e. the individual birds in the flock, for example neuroticism items) arise 'solely' because all components depend on the same underlying trait (i.e. the invisible bird, for example neuroticism). Figure 1 shows an application of this model to the Big Five dimensions as measured with the NEO-PI in 500 first year psychology students at the University of Amsterdam (see Dolan, Oort, Stoel & Wicherts, 2009). Reliance on the assumption of local independence is evident by the absence of any direct connections between items. As such, local independence explicitly prohibits direct causal relations between the components of personality as represented by the items. The model with five latent traits influencing only their respective items—as

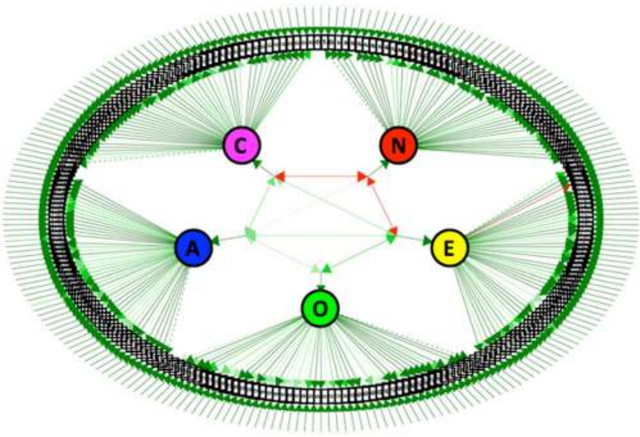

Figure 1. The five-factor model for the NEO-PI items. Covariation between items is explained by the hypothesis that five latent variables (big circles in the middle) act on distinct sets of items (boxes). Positive parameters in the model are green; negative parameters are red. The arrows between circles and boxes represent factor loadings, arrows between circles are correlations between factors and arrows pointing into the boxes represent residual variance. N, neuroticism; A, agreeableness; C, conscientiousness; O, openness; E, extraversion.

depicted in Figure 1—does not fit the data ($df = 28430$, $\chi^2 = 60839, p < .001$), which is mainly due to violations of simple structure: particularly, the correlations between items that belong to different personality dimensions are too high to be accounted for by the model. How can one address this problem? One way, the standard way in personality psychology (e.g. Savla, Davey, Costa & Whitfield, 2007) is by tweaking the model 'on the basis of the data' so that the basic latent variable hypothesis is preserved (e.g. by allowing cross-loadings, exploratory factor analysis with procrustes rotation; see also Borsboom, 2006 for an elaborate critique). Another way would be to make the simple structure model more complex, for example, by introducing first-order and second-order latent variables (not to detract from the main aim of this paper, we have not included fitting such more complex models). Another way, the central tenet of this paper, is to consider the misfit of the untweaked model, an indication that the latent variable hypothesis fails as an explanation of the emergence of normal personality dimensions, and to move on towards alternative models.

That is, because of the local independence assumption, the very idea of cognitive, affective and behavioural components (i.e. items) that are directly connected to one another for causal or homeostatic reasons (or, for that matter, because of logical ones) is irreconcilable with the dominant latent trait perspective on personality dimensions and their items. If we take the connections between the components of personality to be real, that is, non-spurious, then a viable alternative approach is to describe them as a network. The crucial aspect of such a network is its organization: the way in which functional components of human personality are linked to one another. In turn, this organization depends critically on the equilibriums of the human system and its environments: certain behaviours correlate or coincide, whereas others do not because they are compatible or incompatible, respectively, with respect to specific equilibriums.

From this point of view, neuroticism items are tightly connected not because they are caused by the same latent

DOI: 10.1002/per

trait (neuroticism) but because they arise in similar equilibriums: for example, someone who feels threatened easily will likely also suffer from nerves, feel lonely and worry too long after an embarrassing experience. Items related to the free exploration of environments (e.g. being open to new people) will unlikely co-evolve within threat-related equilibriums and hence will not be tightly connected to neuroticism items. This is not to say it is no longer valid to speak of 'neuroticism' or 'openness' as personality dimensions/traits: it certainly is, but under the assumption of a network perspective, these terms do not indicate latent causes of behaviour but groups of tightly inter-connected personality components. Thus, we can still use a term such as 'neuroticism' to refer to a phenomenon that emerges as a result of the biological, psychological and environmental forces that knit some behaviours closely together. However, we speak of such a phenomenon just like we speak of a flock of birds. We know that a flock emerges out of the synchronized behaviour of the birds it contains and would not venture to hypothesize that it existed independently of that behaviour, let alone was caused by it (Schmittmann et al., in press).

Naturally, we are not the first to raise questions about the incompatibility of current trait models with dynamic interactions between personality components and the environment. Similar ideas have been manifested in the writings of personality theorists, almost since the inception of the discipline; recent theorists such as Mischel & Shoda (1995) and Cervone (2005), as well as Read et al. (2010), have argued along very similar lines. However, the methodology to study complex networks has been developed to maturity only relatively recently (e.g. Albert & Barabási, 1999; Newman, 2006; Watts & Strogatz, 1998). As a result, we are now able to use such techniques to visualize and analyze large-scale networks in ways that have not been possible before. The remainder of this paper aims to give first passes at applying these ideas systematically in the study of personality. We focus on four illustrations regarding (i) the overall organization of personality components, (ii) the distinction between state and trait, (iii) the genetic architecture of personality and (iv) the relation between personality and psychopathology.

A NETWORK OF PERSONALITY COMPONENTS

Mapping the structure of personality onto a network is a daunting task. Fortunately, we have a reasonable starting point in the form of common personality questionnaires that query respondents for their status with respect to exactly the type of components that would be likely candidates to make up a personality network structure. The correlations between components will tend to be higher when the connectivity in the human system is stronger. Thus, by studying correlations and representing them in a network structure, one may obtain a first glance at the visualization of the global (i.e. average) structure of personality components. We have developed an R-package for network analysis (qgraph: Epskamp, Cramer, Waldorp, Schmittmann & Borsboom, 2011) that is capable of constructing such visualizations directly from the data. In essence, the routines in this package treat a correlation matrix as a so-called weighted network, that is, it treats the items as components and their correlations as the strength of the connections among these components. The result of applying this routine to the items of the NEO-PI-R is represented in Figure 2 (for the large central graph, same sample as used for Figure 1; for the small graph in the top right, simulated data).[2]

A graph like that in Figure 2 offers a powerful visualization that can be used to reveal patterns and structures that would be very difficult to spot by using traditional methodology (note that Figure 2 represents the complex structure of no less than $240 \times 240 = 57600$ correlations with little data reduction). For instance, looking at Figure 2, there are a few things that catch the eye immediately. First, the network is very densely connected, much more connected than would be expected if a small number of latent variables gave rise to the correlational structure (even if we let these five latent variables correlate, as we did in Figure 1). In particular, this visualized pattern of correlations between personality items is not convincingly suggestive of five distinct latent traits. This can also be seen when comparing the empirically constructed graph with the inserted graph at the top right of the figure, which shows the correlations that would be expected if the five-factor model of personality were true (i.e. if the covariation between items could be solely explained by five correlated latent variables that cause the item responses).

In this dataset, the strongest organization arises for neuroticism and conscientiousness items (red and purple nodes/circles in Figure 2). Extraversion and agreeableness items (yellow and blue nodes in Figure 2) are largely intertwined with one another, meaning that, on average, an extraversion item is not much more strongly correlated with other extraversion items than with agreeableness items (and vice versa; difference in average correlations is 0.12). This makes sense from a network perspective. For instance, it becomes easier to spend time with others (agreeableness) if one likes to be around others (extraversion), and it is difficult to talk much with people at parties (extraversion) when one is not really interested in others (reversed agreeableness item).

Another interesting aspect of the graph in Figure 2 is that some items are more strongly connected to other items (those items are placed towards the middle of the graph: e.g. nodes representing item numbers 15, 48, 49, 135 and 229), whereas others are only weakly connected to other items or not connected at all (those items are placed towards the periphery of the graph: e.g. nodes 88 and 239). That is, some items are more 'central' in the network than others (see also Cramer et al., 2010). Without a network representation, one would be very unlikely even to think about a concept such as centrality in this way, let alone think of ways of computing it.

[2]Please note that for this graph, and the other networks that are presented in this paper, the positions of the nodes in the graph are not identified. That is, by using a force-embedded algorithm, the graphs are a two-dimensional representation of networks that are multi-dimensional. In this representation, the position of a node is defined relative to other nodes in the network. The resulting distance in two dimensions between two nodes does not represent the correlation but, rather, is an approximation of the distances in the multi-dimensional network.

DOI: 10.1002/per

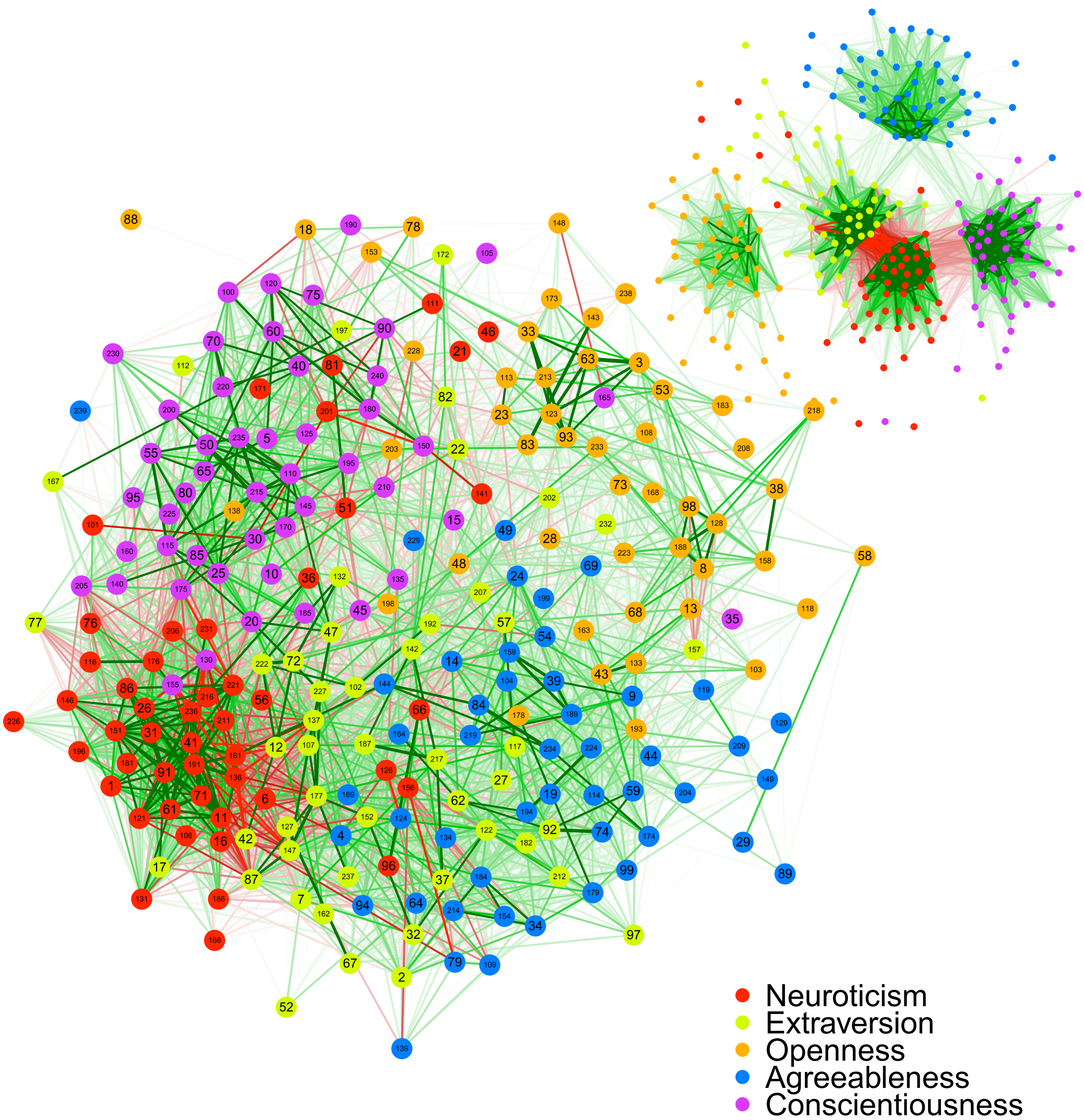

Figure 2. A network representation of 240 NEO-PI items based on data (large central graph) and based on expected correlations if a (fitted) five-factor model were true (i.e. simulated data, small graph top right). Each item is represented as a node, and the numbers in the nodes refer to the item numbers in the Dutch version of the NEO-PI. Nodes are connected by green (red) lines if they are positively (negatively) correlated. The thicker the line, the higher is the correlation. The spring-based algorithm (Fruchterman & Reingold, 1991) used to generate the graph places strongly correlated nodes closely together and towards the middle of the graph.

For example, the item 'When I promise something, one can count on me to fulfill that promise' (node 135) is a central item in the Big Five network. This makes sense because the content of that item is closely connected to not only other conscientiousness items—for example, to fulfil a promise, one generally has to be a reliable person (node 45) and have a tendency to finish things one has started (node 145)—but also items of other personality dimensions as well (i.e. thick lines in Figure 2): for example, someone who likes people and sympathizes with them is more likely to fulfil a promise (agreeableness, node 126) as well as be someone to whom others turn when decisions have to be made (extraversion, node 132). On the contrary, the item 'We can never do too much for the poor and the elderly' (node 89) is a peripheral item: other than a few connections with other agreeableness items—people who care about the poor and the elderly generally feel sympathetic towards people who are worse off (node 209)—(not) caring about the poor and the elderly has (very) little to do with how open, extraverted, neurotic and/or conscientious one is. Thus, items in the Big Five network differ in terms of their centrality in that network, and given the content of the items, these differences in centrality appear to make theoretical sense.

Importantly, the entire notion of central versus peripheral components in the Big Five network is irreconcilable with a latent trait perspective on personality, which is articulated in a latent variable 'measurement' model: in such a model, save for measurement error, items that measure the same trait are exchangeable and thus equally central or peripheral (factor loadings are reliability estimates and as such, cannot be measures of centrality as we view the concept). For instance, if the latent variable model in Figure 1 were true, then someone's position on the conscientiousness continuum could be determined perfectly from knowing the *expected*

DOI: 10.1002/per

value of any one of the conscientiousness items (Jöreskog, 1971; Lord & Novick, 1968; see also Borsboom, 2005). In other words, the model holds that if one knew the expected value of a person, say, on the item 'I tend to finish things once started', then *none* of the other items would offer *any* additional information about how conscientious that person is (i.e. that person's position on the latent conscientiousness continuum). In that sense, all items are equally central (or peripheral), just like mercury thermometers are no more 'central to temperature' than digital or other thermometers are.

Does it matter if some components in the Big Five network are more central than others? It does because, first, it hints at which pathways are more likely to result in the emergence of certain personality structures in some people. A person's personality structure can be represented in a network analogous to the one in Figure 2 (for such an individual network, connection strength then refers to how strongly two personality components are connected over time in one person), a subject we will return to in the next chapter. Because Figure 2 is based on between-subjects data (and is, as such, an 'aggregation' of the networks of all these individual subjects), it is likely that at least in some of these subjects, the central components in Figure 2 are prominent features in their networks as well. The network model predicts that once such a central component becomes 'active' in someone (i.e. a component changes in terms of its state,[3] for example, not having experienced this before, someone starts to experience fear of disappointing others, a component linked to both agreeableness and extraversion, Mongrain, 1993), then the probability of neighbouring components to become active as well rises because of the strong connections of that component with other components in the network (e.g. 'I get chores done right away' and 'I finish things I have started'). This particular pathway (fear of disappointing others ↔ getting chores done ↔ finishing things) to a personality structure in which multiple conscientiousness items are active is then more likely than a pathway to conscientiousness that includes peripheral components (e.g. 'I take voting and other duties as a citizen very seriously', node 35).

Second, centrality matters because it is linked to the ability to change and to how widely spread out the consequences of such change will be. When a personality component is central, it is likely to be dependent on many other components (and vice versa), so it will be more difficult to change. Changing a habit of not fulfilling promises, for example, is more likely to be difficult because to change that component, there are many others that may need to be changed as well (e.g. sympathize more with other people's needs and learning to finish things). Drawing analogy to a trade network, there are tradesmen who operate as pivotal points in the network (i.e. as central nodes): they have a large influence on the total productivity of the network (how much money the network as a whole makes), and it is very difficult to drive them out of business because of their strong connections with so many others (i.e. individual components of personality). It is unlikely but for some reason, it might be that a central component in fact does change (in the trade network analogy, a pivotal person goes out of business). If so, then the consequences for the remainder of the network will be more widespread than if a peripheral component (tradesman on the periphery) changes. For instance, if one ceases to take voting seriously, this is not likely to have major effects on other aspects of one's expression of personality. In contrast, if because of whatever circumstance, one ceases to be a reliable person—as might occur in the early phases of dementia with a deterioration of memory functions—this is likely to have effects throughout the system.

[3]For the sake of simplicity, this papers focuses on activation as a dichotomous characteristic of a personality component: it is either "on" or "off". However, it is also possible to define activation as an ordinal or continuous characteristic, in which components' activation varies along a scale. In this way, components in a personality network can be active with a certain 'intensity'.

NETWORK STRUCTURE AS A SOURCE OF STABILITY

Human actions are flexible and unpredictable across situations, but at the same time, general patterns of behaviour can be extremely rigid and very difficult to change. Theories of personality aim to reconcile these two facts of human life and provide compelling explanations for the stability that apparently underlies the great variability in daily moods, thoughts and behaviours. The traditional way of dealing with this issue is to invoke a two-part explanation in which the variation in behaviour is governed by transient factors, whereas the average around which these variations are dispersed is caused by a stable factor. The latter is typically conceptualized as a trait, defined as a relatively enduring organismic (psychological, psychobiological) structure underlying an extended family of behavioural dispositions (Tellegen, 1991). Thus, in this definition, a 'trait' is a 'common cause', a structure that 'explains' the stable level of functioning around which a certain variability in 'states' revolves (e.g. the trait-state-error model; see Kenny & Zautra, 1995). An example of such a structure is the latent dimension of extraversion, which is thought to cause stability by affecting the chances for a broad range of states to occur, as shown in the left panel of Figure 3.

Both the traditional model in the left panel of Figure 3 and the network in Figure 2 are between-subjects models that—for several reasons—cannot be assumed automatically to generalize to specific individuals (Borsboom, Mellenbergh & van Heerden, 2003; Borsboom, Kievit, Cervone & Hood, 2009). From a network perspective, inference at the level of the individual is possible if one assumes that the dynamic structure of personality components of an individual can be represented in a similar network form (e.g. Figure 4 is an example of such a hypothetical network of an individual). Individual differences can then be captured by allowing for individual differences in components and the strengths of the connections among them.

From a network perspective, there are multiple ways in which trait-like and state-like characteristics can be defined at the level of individual networks (see Figure 4 for an illustration). This flexibility stands in stark contrast to the trait

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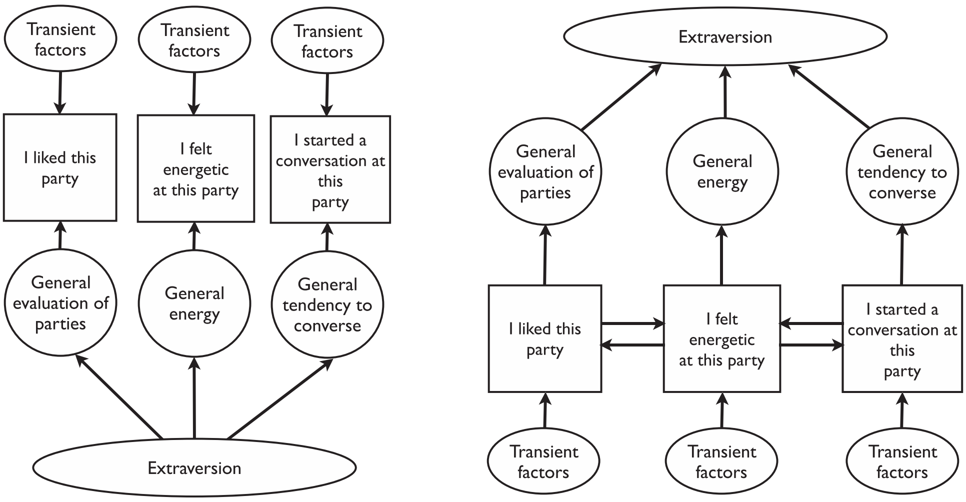

Figure 3. Illustration of the trait view according to a traditional latent variable (left panel) and a network perspective on personality (right panel). From a latent variable perspective, a trait such as extraversion is a common cause of stable dispositions that, together with transient factors, explain momentary states. The network alternative views direct interactions between personality components, influenced by transient factors, as the source of synchronized stability of components. In this view, a trait such as extraversion emerges out of these interactions. Traits are no longer common causes but summary statistics or index variables describing the average activation level of states.

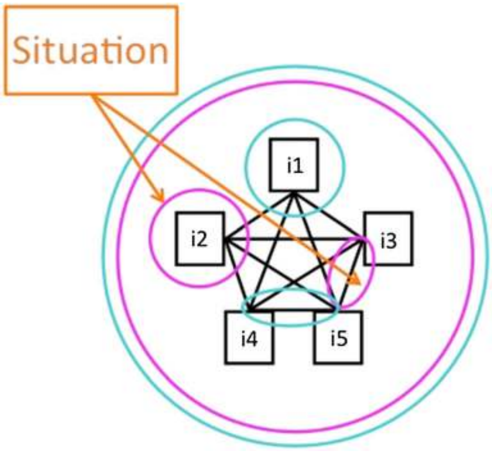

Figure 4. The possibilities of conceptualizing traits and states within an individual's network of five personality components (i1–i5). The pink circles refer to possible conceptualizations of traits, whereas the turquoise circles refer to possible conceptualizations of states in the network. Situations in the environment can influence either individual components or connections among them, thereby changing their states.

view, in which traits and states can only be sensibly defined at the level of the (first-order or second-order) latent dimensions (from a latent trait perspective, it would make no sense to define states and traits at the level of the items, although it might be technically possible). As such, individual differences can only be expressed in terms of that latent dimension as in, for example, 'Alice is more trait neurotic than Bob', whereas the network perspective can express many differences between Alice and Bob, such as 'Alice's network has more trait-like neurotic components than Bob's' and 'The connections in Alice's network are more state-like than Bob's'. Such multiple observations are likely more true to the subtle nature of individual differences.

A first way to define traits and states in a network is at the level of the network as a whole (turquoise circle around the entire network in Figure 4): synchronized stability of multiple components can result in the emergence of a stable trait such as extraversion (as illustrated in the right panel of Figure 3, in this case for extraversion components). That is, instead of the current view that a trait ultimately 'causes' behaviour (i.e. arrows pointing from Extraversion in the left panel of Figure 3), the network perspective views a trait as a phenomenon that is the 'result' of (and, in that sense, emerging from) direct interactions between behaviours as measured with personality items (i.e. arrows pointing towards Extraversion in the right panel of Figure 3). As such, a trait, from a network perspective, is similar to a summary statistic or index variable that describes the average activation level of states, which is consistent with the key assumption of a formative model (see Edwards & Bagozzi, 2000). Importantly, the network perspective is thus 'not' contradictory to current trait theories. Networks result in traits too, the only difference with current trait theories being that in the latter case, traits are most typically explained with a latent variable model in mind. That is, trait theories are currently intertwined with a latent variable perspective (as depicted in the left panel of Figure 3).

Networks can result in traits because transient factors and context determine the activation of affective, cognitive and behavioural components that in turn may activate one another if they are connected in the network architecture. Every time a set of components is activated (e.g. when a person feels energetic), the activation contributes to a self-evaluation stored in memory ('I am an energetic person') that is of the kind queried in typical personality questionnaires ('Would you consider yourself an energetic person?') and serves as evidence for evaluating the self-related hypothesis (van der Maas, Molenaar, Maris, Kievit, & Borsboom, 2011). General evaluations that arise from densely connected areas in the network will covary; as a result, these variables will form a large principal component if submitted to a data reduction technique such as principal components analysis. However, a

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simple structure confirmatory factor model (like that in the left panel of Figure 3) may not fit well because of violations of conditional independence (i.e. because the model does not get the causal structure right). We understand this to be typical in personality research where confirmatory models can fit badly even though principal component structures are robust and replicable (McCrae, Zonderman, Costa, Bond & Paunonen, 1996).

A second way in which networks can display trait-like and state-like properties in individuals' networks is at the level of these individual components themselves (turquoise and pink circles around the item boxes in Figure 4). Roughly speaking, there are two reasons why components can display both trait-like and/or state-like features. First, the wordings of the items themselves may or may not refer to stable behavioural dispositions. For example, the Big Five network presented earlier (Figure 2) contains many components that refer to stable behavioural dispositions (e.g. 'I easily feel offended by other people' and 'I finish things once I have started them'), whereas the responses to other items may greatly vary over time (e.g. 'I feel offended now' or the items represented in Figure 5). The latter components can be considered to be inherently more state-like, whereas the first are inherently more trait-like. Second, the activation of components can be altered (from 'active' to 'not active' or vice versa), depending on a specific 'situation' a person is in (orange arrow from situation to i2 in Figure 4). Some of these components are more state-like because alterations in the environment (i.e. different situations) result in unstable activity patterns (i.e. the change in activity is relatively temporary). For example, a component such as 'I'm full of ideas' can be unstable in certain people: the component would be active (i.e. Alice feels full of ideas) for Alice after a positive day at work during which her boss complimented her on having a good idea but inactive (i.e. Alice does not feel full of ideas) the next day because her mother-in-law describes her, in her face, as a follower and not a leader. In contrast, some situations result in long-term stable changed activity in one or more nodes. For example, Bob, a trusting person, obtains a venereal disease from his cheating girlfriend who also dumps him. Subsequently, Bob re-examines basic assumptions about how he sees the world and as a result, changes: becomes less trusting, more suspicious of the motivations of others and so on.

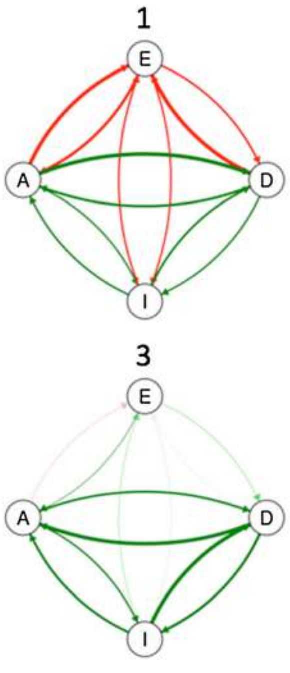

Figure 5. Network representations of the temporal dynamics of four individuals (1, 2, 3 and 4) who were repeatedly assessed in an experience sampling study. An arrow from, for example, node A to node I represents the correlation between the score on node A at time t with the score on node I at time $t+1$: green (red) lines represent positive (negative) correlations. The thicker the arrow, the stronger the connection. E, pleasantness of the event reported to be most important; A, anxious; D, feeling down; I, irritable.

Situations can also influence the connections among the components (orange arrow from situation to the connection between i1 and i2 in Figure 4; analogous to moderation). Connections subject to such influences can be more susceptible to change and thus more state-like in that they are aspects of personality that vary in response to different situations (analogous to what is hypothesized in the CAPS model: Mischel & Shoda, 1995, 1998). For example, Bob normally does not feel guilty because he sometimes feels just miserable for no reason (i.e. relatively stable weak connection between feeling miserable and feeling guilty). But, when Bob feels just miserable right when his wife surprises him with tickets for a cruise, he feels incredibly guilty: that is, the connection between feeling miserable and feeling guilty is stronger, triggered by the situation. It is, on a related note, this very malleability of certain connections that is the focus of many psychological treatment strategies (e.g. cognitive behavioural therapy; see Cramer et al., 2010). Other connections are likely relatively trait-like, in part, because the components they connect are inherently more trait-like as well, for example, the connection between 'I like to go to parties' and 'I feel comfortable around people'.

The empirical study of this dynamic structure of personality networks becomes possible through the use of time-series data. For instance, Figure 5 presents empirical correlation networks of four people who participated in a larger study into the effects of mindfulness training on a range of emotion and psychopathology variables (Geschwind, Peeters, Drukker, van Os & Wichers, 2011; see Appendix A for a description of the sample and the measures). The participants in this study were assessed multiple times a day by using an experience sampling protocol, which generates series of observations over time. The networks in Figure 5 represent the lag-1 correlations between time series of four variables: anxiety, feeling down, irritability and the pleasantness of the event reported to be the most important one during the assessment period. Specifically, a thick green arrow from A to I means that a higher level of anxiety at t predicts a higher level of irritability at $t+1$, a thick red arrow from E to A means that a more positive evaluation of the event that took place at t predicts a lower score on anxiety at $t+1$ and so on. Naturally, it is also possible to construct such intra-individual networks for correlations within the same time frame: the construction and interpretation of such graphs would be analogous to the procedure explicated for the inter-individual network that was presented in Figure 2.

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The individuals showed marked differences in their dynamic structure. Individual 1, who is relatively typical for the sample studied here, showed positive dependencies among A, I and D: for example, the more anxious at t and the more irritable at $t+1$ (and vice versa). A, I and D all had negative dependencies with E: for example, lower anxiety at t predicted higher pleasantness of the event reported at $t+1$, but a more pleasant event at t also predicted lower anxiety at $t+1$. This appears not to be the case for individual 2 whose relations between E and the psychological variables were one-way traffic: for example, lower anxiety at t predicted higher pleasantness of the event at $t+1$, but a more pleasant event at t did not appear to predict lower anxiety at $t+1$. One might speculate that this individual 'profits' less from positive events. Participant 3 also showed this pattern but in addition showed no noticeable predictive relation between the psychological variables at t and the pleasantness of the event at $t+1$. This individual thus appeared to function independently of the events reported in the relevant time. Finally, participant 4 showed a surprising pattern of purely negative relations, in which the anxiety variable functioned as a source node without substantial incoming effects and seems to steer the other variables in a counterintuitive way ('increased' anxiety at t predicted 'decreased' irritability and depressed mood at $t+1$, whereas 'decreased' irritability and depressed mood at t predicted a 'more' pleasant event at $t+1$). We do not know, from the present data, to what extent these patterns generalize outside the studied time window or whether they have meaningful connections to the everyday functioning of the studied individuals. However, the differences between the network structures are quite suggestive and may, in future research, be shown to have significant consequences.

Thus, from a network perspective, the components of individuals' personality networks as well as the connections among them can exhibit trait and/or state-like properties, in part influenced by situations that figure as separate nodes in the network (see also Figure 4), and traits such as extraversion, or openness, emerge out of the combined activity of the components of the personality network, instead of being the common cause of these components. Traits as emerging entities are not in violation of some definitions of traits: for instance, the definition of Tellegen (1991) of traits as 'enduring [...] structure[s] underlying an extended family of behavioural dispositions' would in fact seem neutral on whether the structure in question is a latent dimension or a network structure.

Understood in this way, the network perspective offers a possible resolution between trait approaches and situationist approaches that emphasize that traits can be adequately described as situation-relevant reaction patterns (e.g. Mischel & Shoda, 1995): the connections among situational nodes—external to the human system—and components that are more internal to the human system are likely to differ in strength across individuals. Such differences in situation behaviour associations lead to if-then signatures of the kind identified by Mischel and Shoda (1995).

Given the ample opportunities for individual differences to arise in a personality network structure, is it in fact possible that 'both' stable individual differences 'and' significant day-to-day variation arise from the same network structure? The answer is yes. To illustrate this, Figure 6 shows three simple networks, representing three fictitious people, consisting of three binary nodes (i.e. nodes that can be either 'active': 1 or 'inactive': 0). All variables are 'measured' at multiple time points but without implying any direction of causation (i.e. all variables influence all other variables). Thus, each resulting network is an intra-individual representation of how three variables influence one another bidirectionally over time. The only differences among these

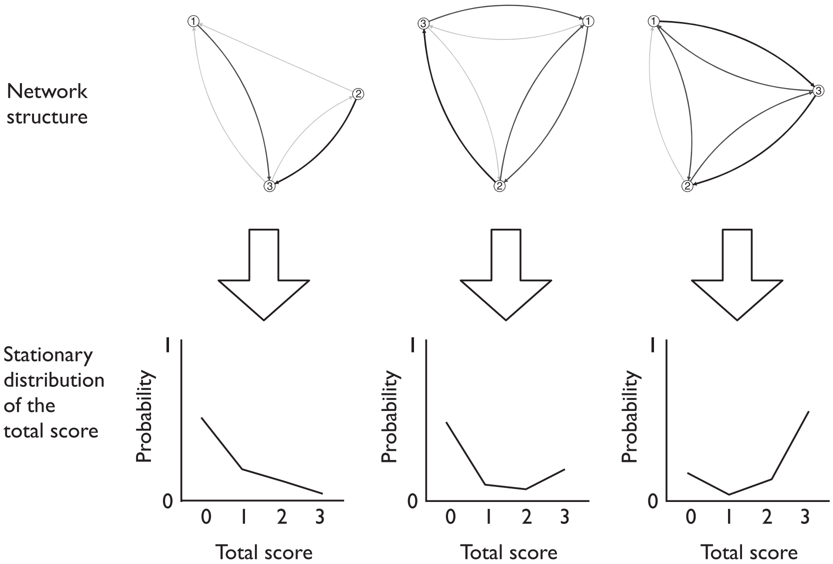

Figure 6. How network structures can lead to stability. The three network structures at the top of the figure, each representing a fictional individual, differ in connection strength: the darker a connection between two nodes, the stronger that connection. These structures generate stationary distributions at the bottom panel. The stationary distribution depicts the probability (y-axis) that, at a randomly chosen time point, a given number of components/nodes (x-axis) is active. These distributions are themselves stable over time, so if the number of active nodes were measured at repeated time points, the resulting scores would show high test–retest correlations.

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networks are the strengths of the connections among the nodes (i.e. each connection has a certain weight that determines its strength): the rightmost network in Figure 6 is the most strongly connected, whereas the leftmost network is the least strongly connected. At time point t, whether or not a node is active is dependent on the status (0 or 1) of each of its neighbours times the relevant connection weight, which results in a total incoming effect A. The probability that the node is active then depends on the total incoming activation as follows: $P(\text{node active}_{t+1}) = 1/(1 + e^{A}{}_{t})$ (note the similarity of this equation to equations in item response theory; e.g. Lord, 1953).

If we simulate data points according to this model for the three networks in Figure 6, the networks will all transition between activation patterns in a random fashion. That is, there will be significant ('day-to-day') variation in which nodes are active or inactive. On the other hand, the probability distributions of the total activation scores (i.e. the total number of nodes that are active at a randomly chosen time point for each network) will be stable: in Figure 6, the average activation level of the leftmost network will be lowest, whereas that of the rightmost network will be the highest, and this is no surprise, given the fact that those networks are weakly and strongly connected, respectively. Thus, stable individual differences in average activation levels are possible as well, and it is exactly that synchronized activity of consistent patterns of node activation within individuals may give rise to traits: if Figure 6 represented openness networks, then the person with the rightmost network would likely be an open person—because, on average, many openness nodes are active at the same time—whereas the person with the leftmost network would likely not be an open person. So given this potential of individual differences in network structure to generate both traits and day-to-day variations without invoking any latent dimensions, what, in turn, could cause these differences in network structure?

THE GENETIC ORIGINS OF PERSONALITY NETWORKS

Genes influence many human characteristics, and personality is one of them. Multiple studies have shown that personality dimensions are at least moderately heritable (Boomsma, Busjahn & Peltonen, 2002; Bouchard, 1994; Jang, Livesley & Vernon, 1996; Kendler & Myers, 2010; Riemann, Angleitner & Strelau, 1997; Loehlin, 1992): for example, 40% of the phenotypic variance in extraversion can be explained by additive genetic factors.

Assigning one number to represent heritability of any particular personality dimension makes sense from a latent trait perspective: items are no more than indicators of a common underlying trait, say, extraversion, and as such, what is transmitted via genes from one generation to the next is the predisposition for developing that personality trait not the propensity for a particular type of behaviour/emotion/cognition as measured with a single item (i.e. personality component; see the left panel of Figure 7). In analogy with height, height is a latent trait (i.e. height is an unobserved variable for which we need measurement instruments to

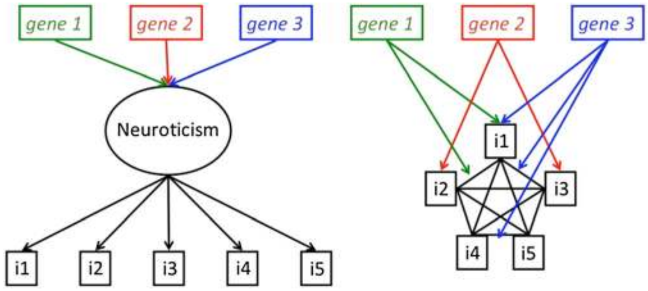

Figure 7. The influence of genes (green, red and blue boxes) on neuroticism according to a latent trait perspective (left panel) and a network perspective (right panel) on personality. Left panel: genes influence the individual items (i1–i5) not directly, only indirectly via the latent trait 'Neuroticism'. Right panel: genes influence the individual items and connections between them directly.

quantify it in individuals; see Bollen, 2002; Borsboom, 2008b),[4] which is measured with various methods (e.g. measurement tape). What is heritable is relative height itself—that is, children of tall parents tend to be tall as well—not any particular measurement of height.

One can go one step beyond defining heritability as a characteristic of a personality dimension such as extraversion (whether it be a latent trait or an emerging feature, as it is defined in a network model), namely, by defining heritability as genetic influence on the individual components of the network and the connections between these components (see the right panel of Figure 7). For example, it might be that liking parties is 20% heritable, whereas enjoying the company of other people is 65% heritable, the difference not being due to differences in reliability (consistent with a latent independent pathways model). Likewise, it could make sense to say that the degree to which people who are quick to understand things have a tendency to be full of ideas (i.e. connection strength between these two components) is 34% heritable or the degree to which people who regularly feel just miserable have a tendency for suicidal ideation (and vice versa) is 78% heritable.

Now, if the network perspective is accurate in portraying personality, then current techniques for the next step in behavioural genetic research, that is, the identification of genes that are the driving forces behind these heritability estimates, might prove problematic. Current techniques employed in genetic association studies typically rely on a sum score (e.g. the sum of the neuroticism item scores of the NEO-PI) as a proxy for the latent variable, neuroticism in this example. Genetic association studies in their most rudimentary form identify genes or genetic variants as being associated with a particular personality dimension if they predict the sum score (i.e. the dependent variable in the design; Cramer, Kendler &

[4]Some may argue that height is not an appropriate example of a latent variable. However, see these papers for an explication of the point that latent variables are variables that are not directly observed (i.e. we cannot observe directly whether someone is 5.1 ft or 5.2 ft). We therefore need measurement instruments to quantify such variables. Also, for example, Harman (1960) argued that a latent variable is an underlying variable that helps explain why certain other variables correlate (i.e. two methods to measure height in Bob correlate because they are caused by the same underlying variable, namely Bob's height). In both non-formal views of the theoretical status of a latent variable, height is an appropriate example.

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Borsboom, 2011; van der Sluis, Kan & Dolan, 2010). If personality dimensions were indeed latent traits, this approach is sensible, although not necessarily optimal (van der Sluis, Verhage, Posthuma & Dolan, 2010).

To date, standard genetic linkage and association studies have not yielded any clear genetic candidates: for the Big Five personality dimensions, many candidate gene findings are not replicated, and the genetic polymorphisms that are consistently identified typically account for less than 2% of the genetic variance (Amin et al., 2011; de Moor et al., 2011; Fullerton et al., 2003; Kuo et al., 2007; Nash et al., 2004; Terracciano et al., 2010). This discrepancy between moderately high estimates of population heritability and the inability to identify the responsible genetic polymorphisms is called the 'missing heritability' problem, a problem that is pervasive throughout the entire realm of psychology as well as other complex biomedical traits such as height and blood pressure (e.g. Maher, 2008; Manolio et al., 2009).

Although many explanations have been put forward for this missing heritability problem (e.g. additive small effects of many individual genes, limited sample size, population stratification and selection bias; Frazer, Murray, Schork & Topo, 2009; Maher, 2008; Sullivan, 2011), we focus on another possible reason: misconceptualization of the phenotypic model (Figure 7). In particular, the model in the left panel of Figure 7 might be wrong (as was, for example, recently shown for nicotine dependence where two genes influenced individual symptoms quite differently: Maes et al., 2011). From a network perspective (the right panel of Figure 7), it is not likely that all components and connections between them in the personality network are influenced by the exact same set of genes (see the right panel of Figure 7: gene 1 influences other parts of the network than gene 2). For example, components such as feeling sad and finding political discussions boring probably involve different antecedent pathways: feeling sad has more to do with emotional processes, whereas finding political discussions boring is more likely a cognitive phenomenon, and as such, feeling sad and finding political discussions boring probably involve different biological substrates and pathways and thus different genes. If so, then attempting to relate genetic polymorphisms to their sum score is not likely to contribute to effective gene hunting because with a sum score, one only captures the genetic variance that is shared among the components and their connections (van der Sluis et al., 2010): the power to detect effects from single-nucleotide polymorphisms (SNPs) in sum scores is multiple times lower when these gene effects are local (e.g. gene 2 in the right panel of Figure 7 influences two neuroticism items) compared with when these effects are global (e.g. gene 1 in the left panel of Figure 7 influences all neuroticism items via the latent trait 'neuroticism').

It is hard to pit the models in Figure 7 directly against each other because estimation and fitting algorithms for the network model have not been developed in sufficient detail. However, we can examine and test divergent predictions of the models such as the location of the effect of SNPs: from a latent trait perspective, one would expect SNPs impact at the latent trait level, whereas from a network perspective, one expects SNPs to impact at the level of the individual components (see Maes et al., 2011).

We tested this prediction by using data from 1625 healthy individuals who participated in the dbGAP GAIN Major Depression Disorder study (dbGAP study accession, phs000020.v2.p1). In particular, we investigated the effects of seven top SNPs that were implicated in neuroticism in two recent genome-wide association studies (de Moor et al., 2011, Terracciano et al., 2010). We tested whether the effects of these genes on the item responses were most likely to be mediated by the latent trait 'neuroticism' or whether these effects were more likely to be item specific (see Appendix B for an extended description of the sample and the method).

The analyses showed that in this sample, none of the seven top SNPs had a significant direct influence on the latent trait 'neuroticism'. On the one hand, this result can be interpreted as a non-replication of these SNPs in this sample, which could be due to a limited sample size or the use of a different neuroticism instrument (see Appendix B). On the other hand, the result can be interpreted as lack of support for a latent trait perspective on the influence of genes on personality dimensions. At the same time and in support of the network perspective, we did find evidence for significant direct influences of three SNPs (rs17453815, rs12509930 and rs7329003) on three individual neuroticism items ('restless, can't sit still', 'guilty' and 'sleepless due to thought racing': see Figure 8). These effects were significant at $\alpha = .005$ (p-values for the SNP-latent trait 'neuroticism' ranged between .16 and .62; see Appendix B). Naturally, replication of these specific SNP-item relations in other, larger samples is imperative to draw definitive conclusions. This example with real data mainly serves to illustrate how to test the diverging predictions from the latent variable versus the network perspective.

Another way of testing the viability of the latent trait perspective is to check whether the directions of the effects of the seven top SNPs (i.e. increase or decrease risk) are the same across the individual neuroticism items. If the latent trait perspective is correct and genes influence individual items only indirectly via the latent trait 'neuroticism', then all relations between an SNP and identically coded neuroticism items should have the same sign. This, however, is not what we found in this data set (see Table S1 in Appendix B for the odds ratios (OR) between SNPs and neuroticism items and p-values computed according to false discovery rate criteria). For example, SNP rs17453815 was associated with a decreased risk for being 'easily irritable' (OR = 0.69; $.01 < p < .05$) but with an increased risk for 'restless, can't sit still for long' (OR = 1.32; $.001 < p < .01$). Similarly, SNP rs11707952 was associated with a decreased risk for 'experiencing mood swings' (OR = 0.73; $.01 < p < .05$) but also with an increased risk for 'not feeling your old self' (OR = 1.22; $.01 < p < .05$).

Given that the current methodological state of affairs does not allow for a direct statistical test, psychometric modelling with genetic data might provide a fruitful avenue to explore the feasibility of latent trait versus network models because these models come with specific predictions that can be tested in a confirmatory factor analytic framework. As

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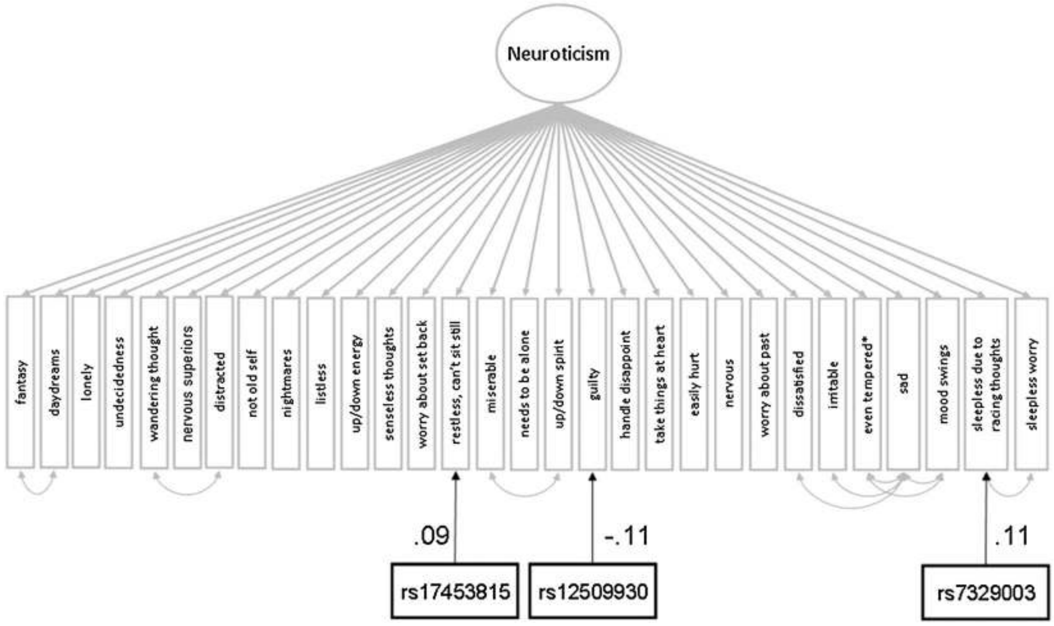

Figure 8. The phenotypic latent variable model relating the latent neuroticism factor (grey circle) to 30 neuroticism items (grey boxes). In black are the significant relations of three single-nucleotide polymorphisms (SNPs) (black boxes) with individual items. Relations between the SNPs and the latent neuroticism factor were not significant. Two-sided arrows represent correlations; one-sided arrows represent regressions. The impacts of the SNPs on the neuroticism items are expressed as standardized regression weights.

such, we do not take the aforementioned results to signify anything definitive about SNP effects on neuroticism items; rather, these results serve as concrete examples of how one might go about testing predictions of the two competing models. It might be argued that finding local effects (i.e. SNP effects on individual items) is not in violation of the 'statistical' aspects of the latent trait model. Although this is true, the 'theoretical' notion of a latent variable as an accurate reflection of personality dimensions is much harder to maintain in the face of genetic effects whose impact is not at that latent level but, instead, at the item level.

If future evidence favours the network model, the next step would be to wonder how personality networks are tied to psychopathological phenomena. As we have argued in earlier work (Borsboom, 2008a; Cramer, Borsboom, Aggen & Kendler, 2011; Cramer et al., 2011; Cramer et al., 2010), mental disorders can also be understood in terms of networks of interacting 'symptoms' (e.g. insomnia fatigue → concentration problems). Because it is well known that certain personality dimensions predict the development of certain forms of psychopathology (e.g. Hettema, Neale, Myers, Prescott & Kendler, 2006; Kendler, Gatz, Gardner & Pedersen, 2006; Terracciano, Lockenhoff, Crum, Bienvenu & Costa, 2008; van Os & Jones, 2001), how might this covariation arise from a network perspective?

THE ROADS FROM PERSONALITY DIMENSIONS TO MENTAL DISORDERS

Some aspects of personality are correlated with the onset and/or maintenance of certain mental disorders: for example, (i) trait neuroticism and major depression (MD), (ii) alienation (a tendency to feel mistreated, victimized, betrayed and the target of false rumours) and substance dependence and (iii) high negative emotionality (a propensity to experience aversive affective states) and antisocial personality disorder (e.g. Klein, Kotov & Bufferd, 2011; Krueger, 1999; Krueger, Caspi, Moffitt, Silva & McGee, 1996). From a latent variable perspective—in which a personality dimension and a mental disorder are latent entities—there are three ways in which personality features (P) and mental disorders (M) can be modelled (see Figure 9): (i) models in which P and M are not causally related in whatever shape or form. Instead, P and M are correlated because they are (partly) influenced by the same etiological processes (the A arrows in Figure 9); (ii) models in which P is an effect

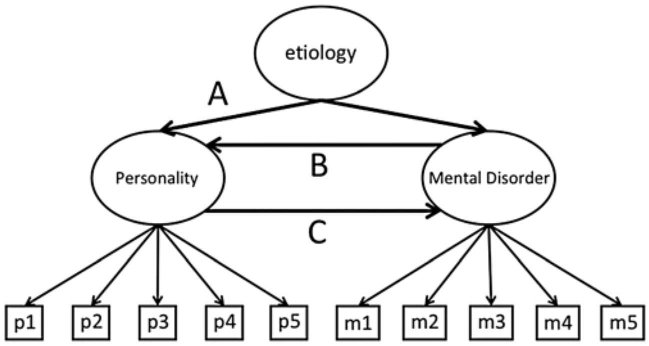

Figure 9. Three ways of modelling the relationship between a personality dimension and a mental disorder. In all three models, personality dimensions (P) and mental disorders (M) are hypothesized to be latent variables (ovals) that have causal influence on the items that are used to measure these variables (p1–p5 for personality and m1–m5 for mental disorder). The models hypothesize that either (A) P and M are related via common etiological processes, (B) P is an effect of M or (C) P precedes M.

DOI: 10.1002/per

of M (the B arrow in Figure 9); and (iii) models in which P precedes M (the C arrow in Figure 9).

From a network perspective, the three classes of models as depicted in Figure 9 do not work because in both personality and mental disorder networks, there are no latent variables. Because items are at the heart of personality networks and symptoms at the heart of mental disorder networks, the most sensible way to conceive of relations between the two networks is by means of direct relations between these items and symptoms (see blue lines in Figure 10). Instead of one option for three types of pathways between personality and psychopathology (i.e. A, B and C model in Figure 9), each blue line between an item and a symptom in Figure 10 represents an optional pathway that could be of the A, B or C type. For example, in Figure 10 (without implying causality because there are no arrows in the figure), one pathway from personality to mental disorder (and vice versa) could be: p2–p4–m5 or, alternatively, m2–p3–p5. That is, from a network perspective, pathways between items and symptoms indicate dependencies between them, such that one may activate another, analogous to how diseases spread through a population. For example, the tendency to feel nervous around other people (p2) likely increases the probability of spending much time alone (p4), which may result in relatively frequent feelings of anhedonia (m5). The other way around may be an equally likely pathway: prolonged feelings of anhedonia may well undermine the capacity to enjoy the company of other people.

As a starting point, like in Figure 2, correlations between personality items and mental disorder symptoms could be used as quantifications of the strength of the connections between these items and symptoms. Figure 11 shows such a correlation network for neuroticism and MD data obtained from the Virginia Adult Twin Study of Psychiatric and Substance Use Disorders (Kendler & Prescott, 2006; Prescott, Aggen & Kendler, 2000; see Appendix C for a description of the sample and the measures). Some marked differences in connection strengths among the items and symptoms stand out. First, there are clearly two clusters of strongly connected items/symptoms, one corresponding to neuroticism (blue nodes) and the other corresponding to MD (red nodes). Second, some neuroticism items are more

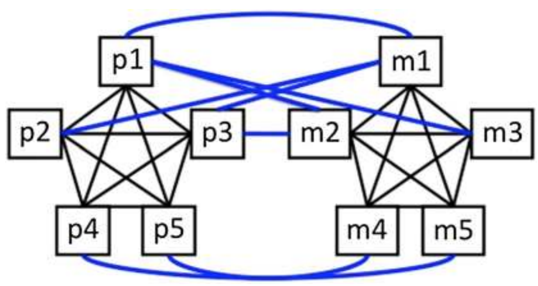

Figure 10. Modelling the relations between personality dimensions and mental disorders. Items from a certain personality dimension (p1–p5) that are connected with one another (black lines) are directly connected (blue lines) with symptoms of a certain mental disorder (m1–m5) that are also connected with one another (black lines).

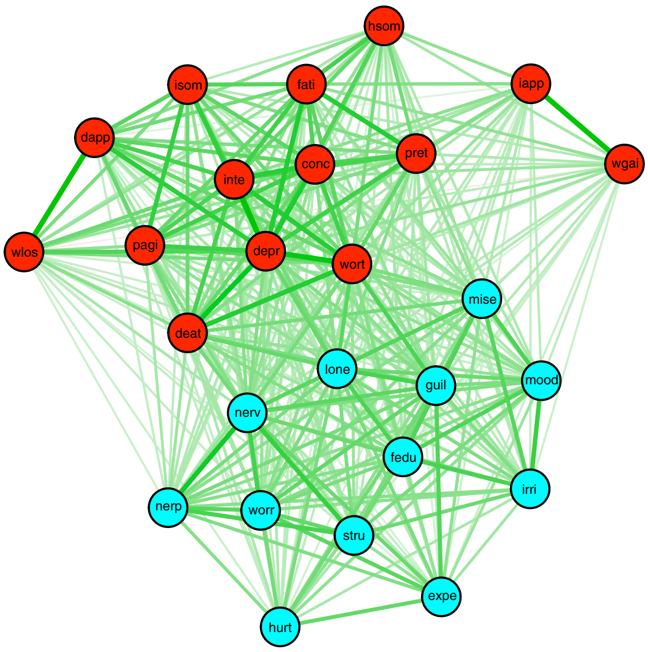

Figure 11. A network based on tetrachoric correlations between the 12 neuroticism items from the EPQ and the 14 disaggregated DSM-III-R symptoms of major depression (MD). The red nodes represent the individual MD symptoms, whereas the blue nodes represent the neuroticism items. Nodes are connected by green (red) lines if they are positively (negatively) correlated. The thicker the line, the higher is the correlation. The same algorithm as in Figure 2 was used to generate the network: the most strongly connected nodes appear in the middle of the figure. Appendix C gives the definitions of the abbreviations.

strongly connected to MD symptoms than other neuroticism items (and vice versa): for example, feelings of worthlessness (wort: MD) and feelings of loneliness (lone: neuroticism) are more strongly connected than one's feelings being easily hurt (hurt: neuroticism) and increased appetite (iapp: MD).

Within a network such as the one in Figure 11, central nodes might be the crucial nodes on pathways connecting neuroticism and MD because such nodes are strongly connected with both neuroticism and MD nodes (as argued earlier in the paper). So for example, in this particular sample, feeling just miserable (mise: neuroticism), being a nervous person (nerv: neuroticism), feelings of loneliness (lone: neuroticism) and feelings of worthlessness (wort: MD) are the most likely candidates for being part of the multiple pathways from neuroticism to MD.

Another way of generating hypotheses about likely pathways from personality to psychopathology (and vice versa) is through 'partial' correlations. The general idea is the same as with simple correlations—one constructs a network with the strengths of the connections between the nodes reflecting the magnitude of the correlations—but partial correlations are potentially more informative about whether two variables are in fact truly related. A high simple correlation between two variables does not necessarily imply that a unique relation exists between these variables. For instance, a high correlation between feelings of guilt and feelings of worthlessness may be due to the fact that both components are influenced by another component in the network, for example, depressed mood. As such, feelings

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of guilt and feelings of worthlessness are not uniquely related; the correlation arises because of their common cause, depressed mood. If that is true, the correlation between feelings of guilt and feelings of worthlessness should be (very) low when depressed mood is controlled, and this is exactly what a partial correlation does: it quantifies the association between any two components while controlling for one or multiple other components in the network. As such, when one computes correlations among the neuroticism and MD items/symptoms while controlling for 'all' other components in the network, a high partial correlation is potentially more indicative of a true relation than a simple correlation. Figure 12 presents such a partial correlation network on the basis of the same data that was used for Figure 11.

A few things stand out when inspecting Figure 12. First, many connections are markedly weaker in Figure 12 compared with connections between the same components in Figure 11, for example, the connection between feelings of worthlessness (wort: MD) and feelings of loneliness (lone: neuroticism): a direct relation between these components might exist (the partial correlation in Figure 12 is not close to 0) but is likely partially influenced by other components in the network (because the partial correlation is lower than the simple correlation). On the other hand, feelings of worthlessness (wort: MD) and feelings of guilt (guil: neuroticism) are almost as strongly connected in Figure 11 as in Figure 12: these two components are likely directly related without being substantially influenced by other components in the network. Second, some pathways from neuroticism to MD (and vice versa) are more likely than others (i.e. are more strongly connected compared with other pathways): for example, a pathway via feelings of worthlessness (wort: MD) and guilt (guilt: neuroticism) is more likely than a pathway via weight loss (wlos: MD) and describing oneself as a nervous person (nerp: neuroticism). When considering which nodes are the most central in this network, the most likely candidates for playing pivotal roles in pathways from neuroticism to MD (and vice versa) are feelings of loneliness (lone: neuroticism), guilt (guil: neuroticism) and worthlessness (wort: MD); thoughts of death (deat: MD), being nervous (nerv: neuroticism) and describing oneself as a nervous person (nerp: neuroticism).

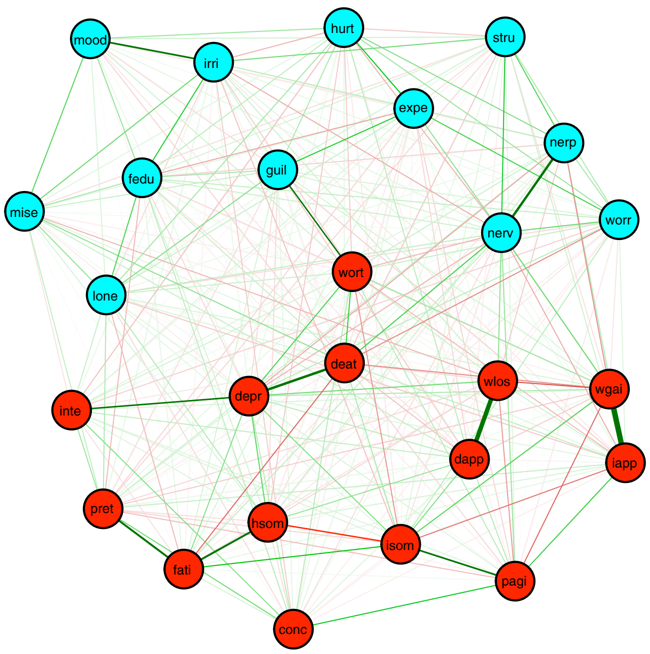

Figure 12. A network based on partial correlations between the 12 neuroticism items from the EPQ and the 14 disaggregated DSM-III-R symptoms of major depression (MD). The red nodes represent the MD symptoms, whereas the blue nodes represent the neuroticism items. Nodes are connected by green (red) lines if they are positively (negatively) correlated. The thicker the line, the higher is the partial correlation. The same algorithm as in Figure 2 was used to generate the network: the most strongly connected nodes appear in the middle of the figure. Appendix C gives the definitions of the abbreviations.

Partial correlations may be used to generate more parsimoneous hypotheses about likely pathways from certain personality dimensions to certain mental disorders (and vice versa), but the technique is by no means bulletproof. It could be, for example, that a connection between two components with a low partial correlation does in fact exist. Sampling error, for example, might result in a low partial correlation between two components, whereas a direct relation in fact exists in the whole population. Therefore, replication of findings in multiple samples is a necessity before any definitive conclusion can be drawn. Another way of testing hypotheses generated by partial correlations in between-subjects data is via longitudinal studies in which these hypotheses are verified in individuals. But instead of focusing on total scores on personality and psychopathology questionnaires—which is the sensible thing to do when a unidimensional latent variable model holds (see Grayson, 1988[5])—longitudinal studies from a network perspective would analyze each item and symptom separately for a prolonged time. In addition, with the time-series techniques explicated earlier in this paper, the temporal pathways among these items and symptoms for individual people may be identified and directly modelled. Such studies undoubtedly will reveal many idiosyncracies—that is, there are likely many ways by which people develop certain forms of psychopathology as results of certain personality characteristics (and vice versa)—but with some strong between-persons partial correlations, we have found in the data example earlier that some important commonalities can be expected as well. As such, the network perspective and its associated investigation techniques may shed light on the exact nature of the complex relation between personality dimensions and mental disorders.

CONCLUSION

In the present paper, we have argued for a novel perspective on personality, in which the cognitive, affective and behavioural components of personality (e.g. liking parties and finding political discussions boring) are related through causal, homeostatic and logical connections. Traits such as extraversion and agreeableness emerge out of these

[5]In every unidimensional latent variable model, the sum score has a monotonic likelihood ratio with the latent variable, thereby rendering the sum score a better approximation of the latent variable than a single item.

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connectivity structures, which implies a radical departure from traditional perspectives in which traits are causes of the relevant components. We have shown how the network perspective may potentially alter our conception of what personality is and may supply new research techniques to investigate (i) overall personality architecture, (ii) state and trait conceptualizations of personality, (iii) the genetic background of personality architecture and (iv) the relations between personality and psychopathology.

Naturally, network methodology is far from fully developed. Examples concern the development of estimation and fitting algorithms for network models, robustness analyses for inferences on network structures, combining inter-individual and intra-individual data and the question of model testing. Pertaining to the latter example, falsifying or confirming a network model can sometimes be quite complicated—for example, a unidimensional latent variable model will fit data that is generated by a network model in which all nodes are bidirectionally connected with equal strength—and sometimes surprisingly easy: for example, if one has the hypothesis that an inter-individual network is mutualistic (i.e. has only positive bidirectional connections so that nodes reinforce one another), then observing a negative correlation is enough to falsify that hypothesis. In its current state, it could be compared with latent variable modelling in the 1950s: we have the ideas and the models, but we still need to overcome many methodological obstacles. Nevertheless, the network perspective offers a plausible candidate model for explaining the 'common' structures of personality and the many idiosyncratic ways in which people deviate from that structure. One of its more attractive features is that the network perspective provides an intermediate position between traditional trait and situationist approaches, which both have longstanding traditions in personality psychology and which both have contributed greatly to our current understanding of personality. The network perspective takes the best of both worlds: it can explain how traits emerge out of the network structure, but it can also accommodate situational influences as external nodes that can activate individual components of the network (or connections among them).

Does adhering to the network perspective mean the end of factor analysis and other techniques associated with the more traditional perspectives on personality? No. Within the network perspective, factor analysis may become a useful technique for identifying groups of closely connected components. In fact, in special cases, it may be possible to estimate certain network parameters through factor analysis because groups of reciprocally connected components can behave exactly as predicted under a factor model (Van der Maas et al., 2006). As such, we do 'not' object to latent variable 'modelling' in which conditional independencies implied by a statistical model are investigated and tested. Also, we readily acknowledge that some of the hypotheses that follow from the network perspective could in principle be tested with latent variable techniques (e.g. testing the influence of genes on individual personality items with independent pathway models) nor do we deny that if some relatively unexplored areas of the latent variable realm would be more extensively cultivated in personality research (e.g. intra-individual factor modelling over time and state–trait modelling within a latent variable framework; Steyer, Schmitt & Eid, 1999), the latent variable model might be equally capable of accommodating certain phenomena compared with the network perspective (e.g. accommodating both inter-individual differences and day-to-day variation).

The question of which techniques are capable of doing what is, in our opinion, not the one that should matter most in personality research. There is and should be no arms race at the level of the (future) technical accomplishments of both models. What matters most is which perspective provides the most plausible account of how personality arises: do traits cause cognitive, affective and behavioural components or do traits emerge from complex interactions between these components? How can future research help in finding an answer to this pivotal question? Given the current lack of methodological sophistication of the network models, the most likely frontrunner in terms of empirical research will be time-series analysis of intra-individual data. Such data can, for example, be collected by assessing individuals' current thoughts, feelings and behaviours at many consecutive time points (for example by means of an experienced sampling protocol, which has been developed in considerable detail in clinical psychology). If time-series analysis of such data would show that, within individuals, personality components have a (bi)directional influence on one another, then this would be strong evidence in favour of the network hypothesis and against the latent variable hypothesis. Another research strategy might be an inter-individual approach, in which one would experimentally test whether manipulating one personality component has an effect on another personality component.

In our view, the reification of factors such as extraversion as causes of individual behaviour is unnecessary and unwarranted in the case of personality. That is, we do not object to latent variable 'techniques' but we do object to a latent variable 'theory' in which the measurement model with a common cause structure is interpreted as evidence for latent causal entities that operate in the minds of individuals, causing all sorts of cognitive, affective and behavioural patterns (see also Borsboom, 2008b). Human behaviour simply does not appear to work this way: it is not extraversion that causes party going; extraversion emerges out of liking parties, liking people and enjoying conversation.

ACKNOWLEDGEMENTS

The work of Angélique Cramer and Denny Borsboom was supported by NWO innovational research grant no. 451-03-068. The work of Sophie van der Sluis was supported by NWO/MaGW VENI-451-08-025 and VIDI-016-065-318. The data used for the genetic analyses described in this manuscript were obtained from the GAIN Database found at http://view.ncbi.nlm.nih.gov/dbgap, controlled through dbGAP accession number phs000020.v2.p1. Samples and associated phenotype data were provided by the Netherlands Study of Depression and Anxiety (NESDA) and the Netherlands Twin Register (NTR).

DOI: 10.1002/per

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DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 432–433 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1867

OPEN PEER COMMENTARY

What Do the Items and Their Associations Refer to in a Network Approach to Personality?

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Abstract: It is hard to judge the potential usefulness of a network approach to personality research because Cramer et al. (2012) mix up applications to one individual, inter-individual differences and intra-individual processes. From each perspective, the network units, their associations and causal interpretations of such associations have a completely different meaning, and it depends on the particular perspective, the level of aggregation and whether one wants to model measurement error whether latent variables have a place in network models in personality research. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: item network; personality assessment

When I read an earlier paper by Cramer et al. (2010) on a symptom network approach to co-morbidity, it immediately struck me that this approach might have interesting applications to personality. The current target paper is a first attempt of doing so although more thought should have been invested in separating different meanings of personality items across different analytical levels. The authors jump back and forth between items tapping into (a) the behaviour (or the motivational or affective state) of one individual (thus, resulting in one score of one person), (b) inter-individual differences in the typical frequency or intensity of such behaviour within a particular situation or across a broader class of situations (thus, resulting in a variable that assigns a score to each person of a sample, which indicates a behavioural disposition) and (c) intra-individual changes of such behaviour across time (thus, resulting in a time series of scores of one individual). Case (b) can be based on direct judgements or on stable parameters of time series such as the intra-individual mean or standard deviation, combining (b) and (c). Thus, the network nodes can have completely different referents, and the indiscriminate usage of the term 'personality component' for (a) and (b) contributes to confusion.

The three different usages refer also to completely different meanings of the edges of the network graphs that connect nodes. In case (a), they may describe logical relations between items such as 'I am on my way to a party' (a behavioural item) because 'I am motivated to go to parties' (a motivational item), but the notion of a correlation has no meaning at this level. In case (b), correlated are inter-individual difference variables, the standard application of personality questionnaires. Here, a network graph is a colourful description of the coefficients in a correlation matrix (Figure 2 of the target article), but it is hard to see whether these pictures *as such* have any surplus value relative to the correlation matrix (although they may, similar to colourful functional magnetic resonance imaging pictures, increase beliefs in a particular causal interpretation of the depicted associations).

Unfortunately, the authors go not much beyond mere description. A convincing case for a network approach could be made if techniques from network analysis yield meaningful characteristics of variables or persons (just as factor analysis yields factor loadings and factor scores). For example, if network-based indices of self-rated personality items would show a higher predictive validity for important real-life outcomes as compared with traditional methods such as a multiple regression using factors or scales as predictors, this would instantly arouse great interest among personality researchers.

Surprisingly, the authors did not seriously discuss how one should deal with measurement error. Should we really measure traits, from very specific situation–behaviour contingencies to broad traits, only with one item? One useful application of the latent variable approach would be to consider networks where the nodes represent latent variables measured with multiple parallel items and the edges represent latent correlations. In addition, dense regions of item networks could be described by latent classes. Thereby, bias due to measurement error in the associations and their causal interpretations could be reduced.

The quest for causality is much more difficult in case (b) than what the authors' examples suggest, which refer largely to case (a). What is the causal relation between the dispositional liking of people and the dispositional liking of parties? Most people may go to parties because they like people, but more interesting from a personality perspective is that the disposition to go to parties may have different causes in different people. Some narcissists, for example, go to parties because they enjoy being the centre of attention, and many in the film business go to parties to raise money for their next film, and these people do not necessarily like other people. Allport (1937) has reminded us that the same behaviour may be due to different traits in different people and different situations. Therefore, the subtitle of the target article seems to be a bit naive from a personality perspective. The inter-individual variation in causal antecedents of the same behavioural disposition makes it highly dangerous to generalize from a plausible causal connection at the level of one 'average' individual (case a) to causal connections at the level of inter- individual differences in behavioural dispositions (case b).

Nevertheless, I like the authors' attempt to deal with questions of causality that have been largely a taboo topic in personality research. However, their current attempt relies too much on associations; it could be much sharpened by applying concepts such as directed acyclic graphs (DAGs) that are increasingly used in epidemiology (see the target article by Lee, 2012, and the excellent discussion of DAGs by Foster, 2010).

I do not want to reiterate my call for a clearer distinction between levels of analysis when it comes to case (c) where intra-individual changes in items are studied (see trenchant critique of generalizing from intra-individual processes to inter-individual differences or vice versa by Molenaar, 2004). Just as an example, consider the authors' claim that 'If time-series analysis ... show that, within individuals, personality components have a (bi)directional influence on one another; then this would be strong evidence ... against the latent variable hypothesis'. If two different behaviours of the same individual rapidly influence each other in both directions of causality over time, such as in clinically relevant vicious cycles of symptoms ('I fear to panic again'), inter-individual differences in the strength of this intra-individual association can be usefully described by a latent variable. This latent variable may be considered as describing a major cause of differences between individuals suffering from clinically relevant versus subclinical fear.

In my view, network approaches to personality as proposed by the authors should be disconnected from a critique of latent variable approaches and evaluated in their own right in terms of their validity for prediction or causal analysis.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 433–434 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1868

On Models of Personality Structure

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Abstract: We suggest that the description by Cramer et al. (2012) of traditional models of personality structure does not perfectly reflect the models actually endorsed by researchers. Personality researchers assume that many variables will have considerable secondary loadings and that the major personality factors will not account for all of the covariation among those variables. A model that includes common factors provides a more parsimonious explanation of covariation among personality variables than does a model consisting of network links only. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: personality structure; latent factors

In their interesting and thought-provoking article, Cramer et al. (2012) have criticized several aspects of traditional models of personality structure and have proposed a 'network perspective' on the relations among personality variables.

In our view, the description by Cramer et al. of the traditional models of personality structure does not accurately reflect the models actually endorsed by personality researchers. First, Cramer et al. describe models of personality structure as if every variable was expected to load on only one latent factor and as if the major factors were expected to account perfectly for the correlations among the variables. They therefore suggest that we should 'consider the misfit of the untweaked model [i.e., without secondary loadings] an indication that the latent variable model fails as an explanation of the emergence of normal personality dimensions' (Cramer et al., 2012, p. 11). But no personality psychologist seriously entertains such a model. Instead, researchers have known for decades that most personality variables show nontrivial loadings on two or more factors (e.g. Hofstee, De Raad, & Goldberg, 1992); in fact, within lexical personality variable sets, secondary loadings are so numerous and so substantial that the optimal rotational position of factor axes is not necessarily obvious. Researchers have also known that a few broad factors can account only for some large fraction of the covariation among personality variables, and not for all of that covariation. The many residual correlations between variables are generally viewed as being attributable to sources such as those described in thoughtful detail by Cramer et al.

The suggestion by Cramer et al. that models of personality structure are based on an assumption of no secondary loadings is perhaps a reflection of the way in which personality inventory scales are computed. Typically, inventories based on structural models produce broad factor-level scales that are computed simply as means of the 'facet'-level variables that define each of the respective factors. But researchers take it for granted that most of these variables will have appreciable secondary loadings, which generally are theoretically appropriate.

Consider these examples of secondary loadings reported for facet scales of the HEXACO Personality Inventory—Revised (Ashton & Lee, 2010). The Diligence and Prudence facets of Conscientiousness have positive and negative secondary loadings, respectively, on Extraversion. Also, the Aesthetic Appreciation and Inquisitiveness facets of Openness to Experience have positive and negative secondary loadings, respectively, on Emotionality. We suggest that both of these results are meaningful: Extraversion presumably facilitates ambitious work but inhibits impulse control, and Emotionality presumably facilitates artistic sensitivity but inhibits intellectual curiosity. We had not tried to predict these loadings *a priori*, but it would be an interesting exercise to find out whether educated lay persons could do so.

We should comment on the concept of latent factors in the context of personality dimensions. We consider a factor as the common element shared by its defining variables (each of which is a specific manifestation of the factor) and as a cause of those variables only in that limited sense (Ashton & Lee, 2005, p. 15; Funder, 1991; Lee, 2012) (and recall, as mentioned earlier, that most variables represent instances of two or more factors in varying degrees). A model of personality structure that includes such factors is far more parsimonious than is a model consisting of network links only, as it provides a far simpler explanation of the bulk of the covariation among items. To take just one example, it is not merely that the tendencies to be organized and diligent and perfectionistic and prudent all influence each other (which they might well do); they are also representatives of a common underlying tendency, which we call Conscientiousness. With regard to the causes that produce variation in the major personality dimensions, we note that there need not be a single causal mechanism responsible for a given

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dimension. Instead, it is quite possible that many causal processes could contribute independently to the variance in that common factor.

Finally, we should mention that if one takes a 'network perspective' in explaining some of the covariation among personality variables, the fundamental questions about the finding of a few 'groups of tightly inter-connected personality components' still remain: Why are there only a few major dimensions of personality variation, and why are *these* the major dimensions? We have suggested some answers to that question elsewhere (e.g. Ashton & Lee, 2007).

ACKNOWLEDGEMENT

This research was supported by the Social Sciences and Humanities Research Council of Canada (grant number 410-2011-0089).

European Journal of Personality, *Eur. J. Pers.* **26**: 434–435 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1869

The Definition of Components and the Use of Formal Indexes are Key Steps for a Successful Application of Network Analysis in Personality Psychology

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Abstract: Conceiving personality as a network provides an interesting theoretical framework and a promising methodological perspective. The application of network analysis to personality psychology however is not straightforward, and some issues require careful consideration. We argue that the definition of components within networks cannot be limited to single items, and more work is needed to reflect the inherently hierarchical and indefinite nature of components. Additionally, we argue that formal empirical indexes must be clearly defined and consistently used to describe properties of personality networks. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: network analysis; network components; centrality; personality

Cramer and colleagues (2012) questioned the idea that latent dimensions of personality reflect underlying causes of behaviour (McCrae & Costa, 2008a) and proposed an alternative theoretical framework in which personality structure emerges from causal, homeostatic and logical relationships among different components. We agree on many basic aspects of this conception of personality as a network and think that it has a sound potential. We confess that, like Cramer and colleagues, we found epistemologically hollow claims such as 'Extraversion causes party-going', especially when Extraversion is measured including these same behaviours that is subsequently deemed to cause. If one takes the definition of causality seriously, there is no question that an *explanans* must be different from an *explanandum*, yet this basic principle is sometimes violated in personality research. From this perspective, a network analysis applied to personality structure opens up the possibility to investigate causes of behaviours, although we think that it is not the only possible approach. For example, there is work on the interplay between states and traits (e.g. Fleeson, 2001; Steyer, Schmitt, & Eid, 1999) that can provide a sound framework for causal analyses in which specific traits are associated to specific behaviours through specific mechanisms at work in specific situations (e.g. Baumert, Gollwitzer, Staubach, & Schmitt, 2011). We would be curious to know how Cramer and colleagues compare their network analysis with state–trait existing theoretical models, an issue that is only hinted at in the closing of their target article. Despite our general agreement with much of this contribution, we focus the rest of this commentary on two unresolved main issues.

1. *What is a component?* While in different applications of network analysis components may be readily defined as, for instance, individuals (Travers & Milgram, 1969), web pages (Albert, Jeong, & Barabási, 1999) or proteins (Vazquez, Flammini, Maritan, & Vespignani, 2003), the definition of components within personality psychology is more complex. From a theoretical point of view, Cramer and colleagues defined components as thoughts, feelings and acts that are associated with a unique causal system. From a measurement point of view, components are equated to single questionnaire items, as opposed to latent variables: Whereas latent variables are conceived as aggregations that emerge from the interconnections of different components, items are meant to reflect directly single basic units of cognitions, thoughts and acts. Even single items however constitute already aggregations of different phenomena that moreover are inextricably connected to the specific way in which they have been measured. One cannot not aggregate but, at best, can decide which level of aggregation is the most informative. This opens up at least three relevant issues. First, different units (components) may be useful for different purposes. Single items may be useful to provide a fine-grained understanding of the dynamic of a personality dimension, but they might also provide unreliable and unstable information. Aggregates of items (e.g. parcels, facets) may imply a loss in terms of definition but a gain in terms of reliability of the findings. Future work is needed to compare the relative merits of network representations at different levels of aggregation. Second, a unit or component does not exist outside of the specific measurement method that is used. Components can be items measured with self-reports or peer reports, behavioural indicators and so on. Each measurement method has advantages and disadvantages, and each provide only partial information about a personality structure. Future work is needed in which multiple methods are used to provide converging evidence of network analyses of a personality structure. Third, given the existence of different levels of

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aggregation of basic components, it becomes not obvious to what extent a network analysis can simply substitute a factor analysis or rather it represents a complementary but not alternative statistical tool. At some level, subcomponents (whatever they might be) will still need to be aggregated. There is the need therefore to articulate the interplay between the two statistical tools.

2. *Network properties*. A researcher properly using factor analysis or similar statistical models would not rely on a graphical inspection to draw substantial conclusions but would consider instead specific quantitative indicators (e.g. loadings). We do not see why it should be any different for a network analysis. Take for instance the concept of centrality. In the target paper, the graphical position of the items within networks is often straightforwardly interpreted as centrality. However, even though the *qgraph* algorithm (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012) allows for an intuitive visual representation of correlation matrices, using the position of nodes within graphs as an index of centrality may be misleading. Position of nodes depends also on the overall graph (e.g. being at the centre of one factor is different than being at the centre of two), and it can be a by-product of a two-dimensional representation of complex relations (Fruchterman & Reingold, 1991). Centrality is not a feature of a graphical representation, but it is better characterized as a class of properties that do not always covary. As an example, in Figure 1, we report a graph generated with simulated data[1] relative to 201 variables. Four clusters of 50 variables each are at the periphery of the graph, while variable 'X' is at the very centre. Note that variable X is highly correlated with only one variable for each of the four clusters (Y1 to Y4) and nothing at all with the remaining 196 variables. We inspected some formal indexes of centrality (Freeman, 1978) by means of R package *tnet* (Opsahl, Agneessens, & Skvoretz, 2010) to verify in which sense variable X is central. Values of weighted degree, betweenness and closeness are reported in Table 1. If we look at closeness and betweenness centrality, variable X is central. However, if we look at degree centrality, X is the most peripheral variable. Moreover, the four variables connected with X (Y1 to Y4) rank second in terms of betweenness centrality far above all other 196 variables, yet they are visually represented nowhere near the centre of the graph. This admittedly extreme example helps to highlight two issues. First, a network analysis should go beyond the inspection of a graph and focus instead on specific quantitative indicators. Second, which one of these indicators is most informative and in respect to what property must be clearly articulated as they can provide entirely different and non-converging information.

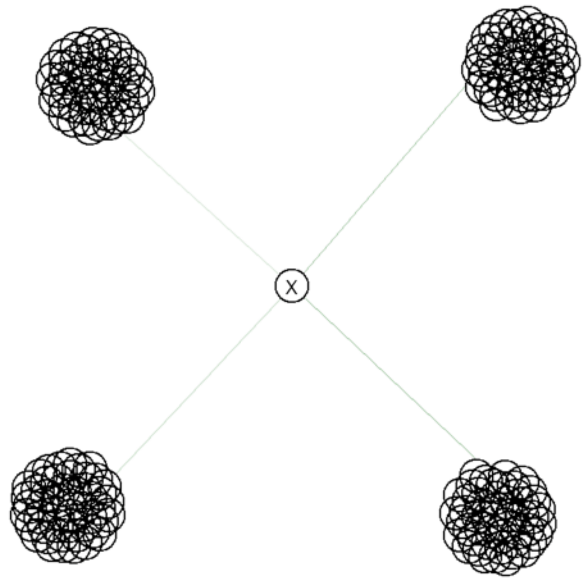

Figure 1. Graph built with qgraph using simulated data.

Table 1. Indexes of centrality of nodes in Figure 1

	Weighted degree	Weighted betweenness	Weighted closeness
Variable X	2.66476	15 000	0.00258
Variables connected to X (Y1 to Y4, $n = 4$)	$M = 40.83619$, $SD = 0.55514$	7399†	$M = 0.00185$ $SD = 0.00010$
Remaining variables ($n = 196$)	$M = 40.85645$, $SD = 0.89010$	0†	$M = 0.00166$ $SD = 0.00007$

Note: Centrality indexes were computed with R package *tnet*, using functions degree_w, betweenness_w and closeness_w.
†The value is exactly the same for all variables.

In conclusion, we are excited by the potential of network analysis and think that it can push the personality field towards important theoretical and methodological advancements, but we also think that substantial work remains to be carried out before it can move beyond being a metaphor to become an actual research tool.

[1]The R code and the correlation matrix are available upon request.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 436–437 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1870

Passing to the Functionalists Instead of Passing Them By

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Abstract: The paper by Cramer and colleagues illustrates how a network approach can model personality systems without positing causal latent factors such as the Big Five. We applaud this effort but argue that nodes should be distinguished on more than quantitative grounds (e.g. displayed centrality or connectivity). To realistically model the affects, cognitions and behaviours that constitute real personalities, organizing constructs such as needs and comparators seems necessary. Incorporating them requires greater consideration of functionalist personality theories that link together environmental features and adaptive behaviour in meaningful and stable ways. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: personality processes; personality measurement; functionalist theories of personality; network approach

Cramer and colleagues have produced a thought-provoking paper that delineates a novel way of conceptualizing personality as a network of behaviours and motivations. They contrast their view with a latent factor approach that assumes constructs derived from factor analysis (e.g. the Big Five) as causal entities, exemplified by a quote from McCrae and Costa that extraversion causes party going (p. 3). Although this conception of the causal power of traits may be consistent with a small number of personality theorists, it is doubtful whether such a radical psychometric view has ever dominated mainstream thinking in personality psychology. Historically, personality questionnaires have gravitated to generating multi-item scales with fairly heterogeneous content to predict variation in a dimension of interest, which is a perfectly reasonable approach to developing scales for purposes such as job selection (e.g. Hogan, Hogan, & Roberts, 1996). However, we agree that this predictive correlation (extraversion predicts party going) may have been conveniently replaced with 'causation' in the heads of some personality psychologists. The approach of Cramer et al. is refreshing by stimulating a badly needed and long-overdue discussion of the proper role of latent factors in personality psychology.

CAN WE SIMPLY REPLACE 'FACTORS' WITH 'ITEMS'?

Although we believe that personality psychology should move beyond latent factors, what is less satisfying is their proposed solution. Cramer and colleagues speak vaguely of 'cognitive, affective, and behavioral components (i.e., items)' (p. 12). Each component is said to be 'not *exchangeable* with other components… [and] has unique causes and effects on other components' (p. 3). However, this notion of exchangeability is essentially quantitative, based on parameters such as the centrality of a node and the number and strength of ingoing and outgoing connections to other nodes. Although they describe the broader class of *personality components* of consisting of *affective*, *cognitive* and *behavioral components*, these narrower classes of personality components receive no special treatment in their model. Rather, somewhat like the dust-bowl empiricist approaches taken by Meehl (1945) and others, all items are basically considered 'grist for the mill' of predicting activity of other nodes or the network as a whole.

The simplicity of this approach is in some ways elegant. However, the apparent requirement of a subset of the items being 'attractors' for the system to maintain equilibrium seems to implicitly acknowledge that certain subclasses of items are required to control homeostatic patterns within the system. Indeed, *several* narrower items classes are likely to be needed to make a network system approximate the various properties of real personalities. Our argument is that these various subtypes of personality components that would be needed are already well described by *functional frameworks* to behaviour, which assume that a person's behaviour is driven in large part by desires to reach certain end states—whether these are hedonic (e.g. achieving satisfaction and avoiding pain), developmental (e.g. graduating from university) or fitness-related (e.g. selecting a mate). As noted by Wood and Hensler (2011), there is a wide array of existing functionalist frameworks in subdisciplines of the behavioural sciences (e.g. Almlund, Duckwork, Heckman, & Kautz, 2010; Carver & Scheier, 1998; Fleeson & Jolley, 2006; Mischel & Shoda, 2005; Pinker, 1997) that converge on a small number of fairly similar classes of personality components to explain the causes and regularities of a person's behaviour. For instance, the negative feedback loops that are necessary to maintain homeostasis—a concept that the authors identify as central to their approach (p. 4)—likely requires at least three distinct types of units: (i) 'comparator' mechanisms (Carver & Scheier, 1998), which in turn monitor the

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discrepancy or similarity between (ii) evaluations of the individual's current state (similar to items like 'I feel alone') and (iii) descriptions of desired states, which are often linked to goals or motives (e.g. 'I like being with people'; Denissen & Penke, 2008). All of these types of personality components show stable variation across individuals; for instance, stable variation in the reward value of social situations is very likely a key personality component that determines whether a person's behaviour (and their total network of other personality components) will look like that of an 'extravert' versus an 'introvert'. When confronting an incongruent situation (e.g. a person who finds social situations rewarding but who is currently alone), individuals can undertake behaviours to re-establish the equilibrium or eliminate the relevant discrepancy (e.g. by calling a friend or going out to a bar; Denissen & Penke, 2012). Such principles ultimately give behavioural patterns an underlying meaning and a functional logic that is missing from the authors' purely stochastic models of node activation.

Of course, functionalist accounts are not incompatible with the proposed network approach. It is probably no coincidence that Cramer and colleagues heavily hinge on motivational constructs such as liking and enjoying at the very beginning (title) and end (last sentence) of their paper. Yet to become fully compatible with functional models, the network approach should more formally describe additional subtypes of nodes that can, among other things, accommodate comparisons of actual situational states from desired states of the type that we have described. We applaud the authors for their self-described 'first pass' at describing how complex regularities in a person's behaviour can originate from very specific personality components rather than from broad latent factors such as those described by the Big Five. However, we believe that the ball now should be passed to the playing field already fairly delineated by many functionalist models of personality. This would allow elaborating a model that captures the actions shown by real personality systems without the use of latent factors such as the Big Five, but it will require a better delineation of the types of personality components needed to attain these complex network properties. Once deeper connections are made between the empirically minded psychometricians and the theoretically minded functionalists, a mutually enriching team play is likely to ensue.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 437–439 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1871

On the Contributions of a Network Approach to Personality Theory and Research

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Abstract: Understanding personality structure and processes is one of the most fundamental goals in personality psychology. The network approach presented by Cramer et al. represents a useful path towards this goal, and we address two facets of their approach. First, we examine the possibility that it solves the problem of breadth, which has inhibited the integration of trait theory with social cognitive theory. Second, we evaluate the value and usability of their proposed method (qgraph), doing so by conducting idiographic analyses of the symptom structure of borderline personality disorder. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: personality theory; network analysis; borderline personality disorder; intra-individual associations

The target article by Cramer and her colleagues (2012) represents some of the excellent work being dedicated to one of the most fundamental issues in personality psychology. Indeed, psychologists have long grappled with questions regarding the structure and functioning of personality.

Thus, we applaud the scope of the work of Cramer et al., and we find much to like about it. For example, we appreciate the attention to differentiated components of personality (Furr, 2009a), the view that within-person associations are potentially important ways in which people differ from each other (Fleeson, 2007; Furr, 2009b) and the importance of resolving apparent discrepancies between social cognitive and trait approaches to personality (Fleeson, 2001, 2004, 2012). Beyond these areas of shared interest, we are excited about two particularly novel and important contributions—one conceptual and one methodological.

THE PROBLEM OF BREADTH

Regarding the conceptual contribution, we are excited that Cramer et al. provided one plausible solution to the problem of breadth (or organization), which has plagued the resolution of social cognitive theories with trait-oriented research. Whole Trait Theory (Fleeson, 2001, 2012; Fleeson & Jolley, 2006) argues that social cognitive theory can provide an explanatory side of traits, that trait-oriented research provides a robust descriptive side of traits (e.g. the Big Five) and that these two sides are fused together into ‘whole’ traits. However, one barrier to achieving this fusion is the problem of breadth—linking a narrowly focused stimulus–response perspective with the apparent existence of broadly defined trait dimensions. Specifically, Big Five traits imply that traits are broad, encompassing a wide variety of behaviours (‘response classes’; Ozer, 1986). For example, the Big Five implies that people who are relatively bold are typically also relatively talkative. In contrast, social cognitive explanations suggest that personality variables are narrowly focused on specific behaviours—for example, there is no reason for high levels of boldness to be generally related to high levels of talkativeness, and bold individuals are just as likely to be relatively quiet as to be relatively talkative. This lack of breadth reflects the fact that social cognitive personality variables are relatively narrow conditionals (Mischel, 2004), in which behaviours are linked to specific triggering situations (e.g. a child reacts with boldness if approached by a peer but reacts with timidity if approached by an adult). From this perspective, there is no reason for a person’s overall levels of any given behaviour to be related to his or her levels of any other behaviour; rather, the overall levels of a given behaviour will depend on the chance distribution of conditionals and situations relevant to that behaviour.

A resolution of these two apparently competing perspectives must explain how narrow situationally conditional responses fuse or accrete into broader traits. The model of Cramer et al. implies one plausible explanation. Specifically, certain responses tend to cause other similar responses, so conditionals that lead to one behaviour will tend to sequentially lead to the other related behaviours, resulting in the accretion of the local dispositions into broad traits. This is clearly not the only accretion mechanism—e.g. Wood and Hensler (2011) proposed another potential mechanism, in which underlying small-sized causes may affect multiple types of responses, and Allport (1937) suggested several additional mechanisms (Fleeson, 2012). Although the data have not yet been produced to test these potential accretion mechanisms, Cramer et al. made a strong case that their network mechanism is statistically consistent with the results of factor analyses revealing the Big Five.

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NETWORK ANALYSIS AS A TOOL

Regarding the methodological contribution, we are excited about network analysis as a tool for discovering new insights, particularly in terms of within-person phenomena. Personality psychologists have long been interested in the structure and processes (or architecture and dynamics, if you prefer) characterizing an individuals' personality, and the proposed network methodology represents a promising path towards this goal.

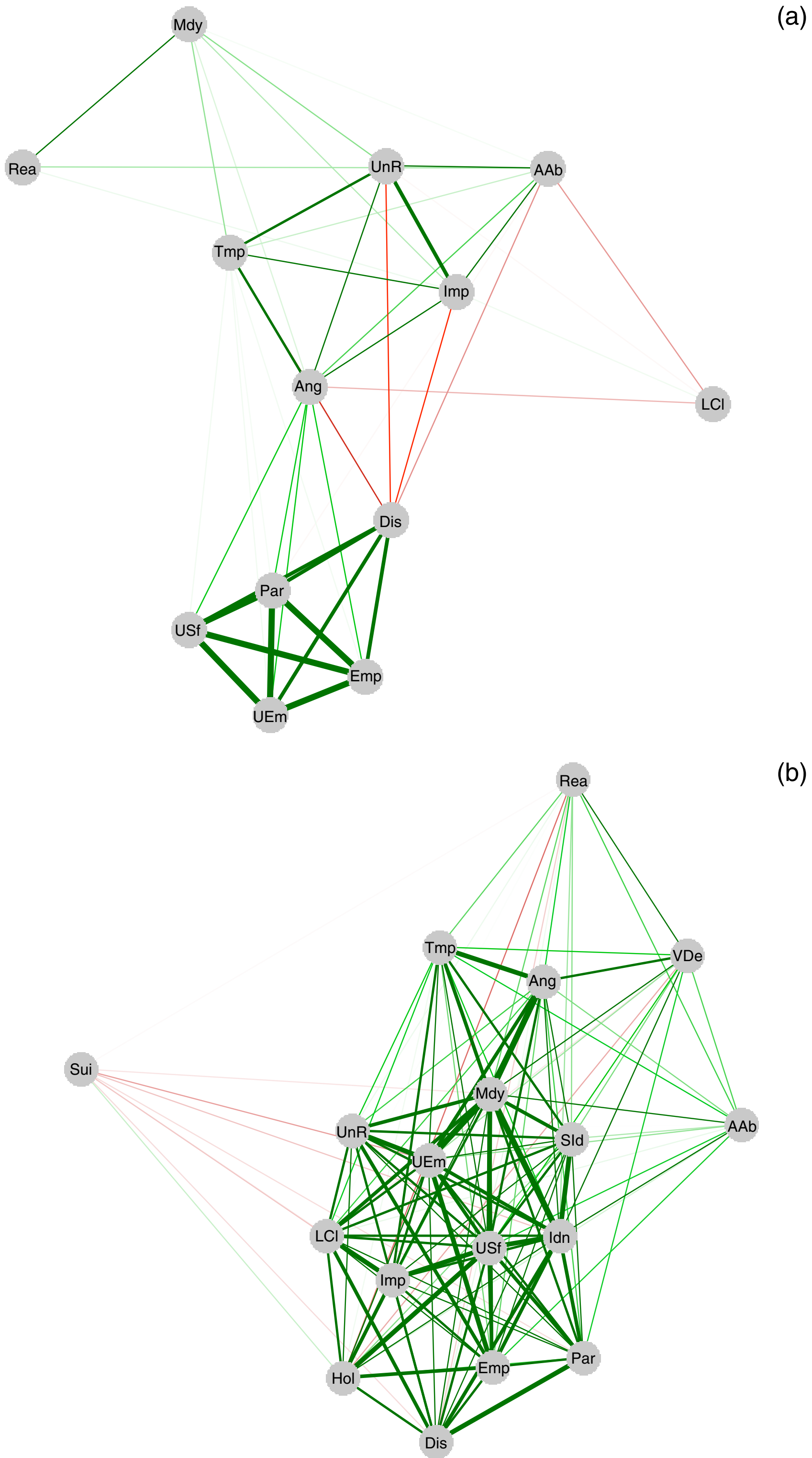

Figure 1. Individual networks among symptoms of borderline personality disorder. Rea = reassure seeking, AAb = avoid abandonment, UnR = unstable relationship, VDe = valuing and devaluing another, USf = unstable sense of self, Idn = identity confusion, LCl = lack of control, Imp = impulsive, Inj = self-injury, Sui = suicidal actions, SId = suicidal ideation, UEm = unstable emotions, Mdy = moodiness, Hol = feel hollow inside, Emp = feel empty, Ang = difficulty controlling anger, Tmp = lost temper, Par = paranoid ideation, Dis = dissociation. This figure is available in colour online at wileyonlinelibrary.com/journal/per

DOI: 10.1002/per

To explore such possibilities, we used the qgraph package of Cramer et al. to examine the within-person structure of borderline personality disorder (BPD). Psychiatric outpatient participants responded to 19 items reflecting symptoms of BPD, doing so (up to) five times a day for seven days (e.g. 'In the last 2 hours, I had difficulty controlling my anger'). Although we are not experts in network analysis or in the use of R software, we obtained findings that can inform the heterogeneity problem in BPD—the question of whether BPD represents a single coherent disorder or a more differentiated disorder that might be highly idiosyncratic (Shevlin, Dorahy, Adamson, & Murphy, 2007; Skodol, Gunderson, Pfohl, Widiger, Livesley, & Siever, 2002).

Consider Figure 1, representing symptom co-occurrence in two participants. Mitt's symptom network (Figure 1a) is characterized primarily by a 'Self-oriented loss of reality' reflecting strong links between Emptiness, Unstable Self, Paranoia, Unstable Emotions, and Dissociation. Other symptoms may occur, but they do so in isolation from this cluster and from each other. In contrast, Newt's symptom network is more broadly interconnected, with relatively strong links among most symptoms. Newt's experience seems to be (nearly) all or none, in that the experience of one symptom seems to correspond to almost all symptoms. Such network-based results demonstrate that heterogeneity (in at least one sense) does indeed exist, and they begin to reveal the nature of that heterogeneity. Of course, for fuller understanding, we must examine the levels of activation of each symptom, along with the patterning across a large number of participants. However, qgraph, with its visual and quantitative output, represents a potentially useful method for examining personological issues having both theoretical and applied implications.

On a more practical note, we should acknowledge some difficulty with the qgraph package. We were unable to coax qgraph into conducting several analyses in which we were interested, and we laboured to understand and overcome problems that emerged. We solved some problems, but we failed to solve others, and the qgraph reference manual was helpful in some instances but not all. Again, we acknowledge having only limited experience with R, and those with more familiarity will surely find qgraph to be more manageable than we did. We look forward to continued development in terms of user-friendliness and documentation, if perhaps only for the benefit of researchers new to R.

ACKNOWLEDGEMENTS

This work was supported by the National Institute of Mental Health Grant R01 MH70571. We thank Ryne Sherman for his assistance with R.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 439–440 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1872

Network Models in the Organization of Personality

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Abstract: The network perspective illustrates an important cautionary point concerning the interpretation of inter-item relationships. However, its complexity comes at a price, including a possible lack of robustness and replicability, and difficulties in interpretation and achieving psychological insight. The most interesting and important manifestations of personality are diverse and consequential behaviours that are related because they really do reflect common underlying traits. Thus, the target article can serve as a reminder of the importance of ranging beyond self-report questionnaires to the much more difficult, expensive and important world of behaviour. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: personality assessment; behavior; network models; latent trait theories; inter-item relationships

The network perspective proposed by Cramer and colleagues (2012) makes an important point. Indicators of personality, such as items on a self-report test, may be related to one another for linguistic, logical or causal reasons rather than because, as in a classic view, they are all influenced by a common, underlying or 'latent' trait. For example, if a test includes an item reading 'I like to go to parties' in addition to an item reading 'I enjoy social contact', then the items are likely to be correlated because parties are significant sources of social contact. For another example, items reading 'I like to take physical risks' and 'I am injured more often than most people' are likely to be correlated for causal reasons; risks may lead to injury.

In the view of personality–behaviour relations underlying classical test theory, behaviours are related to each other only to the degree that they are manifestations of the same underlying trait. An individual's trait score is typically computed as the simple sum (or average) of the trait's behavioural indicators, which are usually self-report items. The relations among items that might arise for linguistic, logical or causal reasons are typically ignored. The network perspective advanced by Cramer and colleagues provides a way to account for this complexity. The overall point made by the target article is reminiscent of Cattell's (1973) concept of 'bloated specifics', which describes a situation in which test items are so similar to one another that the overall score, although highly reliable in a statistical sense (coefficient alpha), may measure a construct so narrow as to be of little importance or interest in any larger sense. The target article may remind us that repeating the same item over and over with small variations is not so different from including items that are nearly synonymous, are logically connected or causally lead to one another. Associations among such items do not necessarily indicate the presence of a common causal trait. Although this point is important, it is not entirely new.

The target article discusses complex network models loaded with numerous nodes and intricate relations, perhaps doing justice to the richness of personality better than simple trait models. However, such complexity comes at a price, running the danger of confusing random error or noise for meaningful patterns of relationships. Even Quek and Moskowitz (2007)—who used empirical event-contingent recording data to validate network models—acknowledged that only by simplifying the networks would their models replicate, leaving each with just a few nodes. Complex models often fit data well, but model selection based solely on fit can result in overfitting, leading to poor replicability and low generalizability. They are also difficult to interpret or to use for psychological insight.

Finally, the data considered by Cramer and colleagues appear largely limited to self-report test items. However, personality is manifested in far more diverse and consequential ways, especially meaningful patterns of behaviour across situations, and over time. Some such patterns of behaviour are, like self-report items, sometimes associated for reasons of semantic similarity, logic or causality. For example, conscientious behaviours are related to longevity not because acting conscientiously and living for a long time manifest the same latent trait but because conscientious behaviours such as careful driving and avoiding binge drinking can extend the lifespan (Friedman, 2011). On the other hand, notice that careful driving and avoiding binge drinking are not related because of any semantic, logical or causal relationship between them but very probably because they both *do* manifest the same underlying latent trait of conscientiousness.

Many other interesting patterns of behaviour can only be accounted for by the existence of a single underlying trait. Years ago, Blum and Miller (1952) showed that children who ate the most ice cream also were prone to seek their teachers' approval more often. There is no semantic, logical or causal relationship between these behaviours, suggesting

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that they might well be manifestations of the same underlying trait (in this case, oral dependency). More recently, Nave et al. (2010) found that children who exhibited unrestrained talkativeness in elementary school displayed dominant and socially adept behaviours as middle-aged adults whereas those who showed adaptability as schoolchildren were cheerful and intellectually curious as adults. Connections among diverse behaviours such as these, widely separated in space, time and eliciting context, are the most convincing way to reveal the underlying, latent traits that remain of central interest to the field of personality psychology. The target article's best service may be its implicit reminder that personality research will make better progress in the future by turning some its attention away from self-report items that are often necessarily inter-related for semantic, logical and causal reasons and towards the overt behavioural manifestations that make personality important (Baumeister, Vohs & Funder, 2007).

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 441–442 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1873

Common Factors and Causal Networks

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Abstract: The target article touches upon some of the most difficult and essential questions in personality psychology. Questioning the notion of a common factor as an as-yet-unobserved common cause of a behaviour domain's exemplars, the authors propose using graphical representations to inspire hypotheses of more complex causal structures. I do not find the case for the de-emphasis of the common factor model to be compelling for those behaviour domains (cognitive abilities) with which I am most familiar. It behoves all personality psychologists, however, to question the foundations of their favoured tools. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: factor analysis; graph theory; behavior domains

The target article brings before us, once again, the question of whether psychometric common factors should play any role in the science of individual differences. Notwithstanding the qualifiers in their conclusion, the authors clearly lean towards *no*.

The alternative advocated by the authors encompasses a weaker and stronger formulation. The weaker formulation is that we may represent the correlations among exemplars of a behaviour domain as an undirected, weighted graph. The description of the algorithm for node placement suggests that (the picture of) the resulting graph is similar to a multidimensional scaling plot (Marshalek, Lohman, & Snow, 1983; Guttman & Levy, 1991). As a stimulus towards further investigation, a less 'lossy' visualization technique than multidimensional scaling can of course raise no objections.

A stronger formulation, although never succinctly stated, is evident in the vivid informal accounts of how different behavioural variables might be causally related. It is here that the authors wade into murkier waters. They first claim that the common factor model—the foundation of mainstream psychometric methodology (McDonald, 1999)—is a *causal* model. That is, the common factor of a behaviour domain is supposed to be a hypothetical, as-yet-unobserved quantity; if an individual's amount of this quantity could be experimentally manipulated, then as a consequence his or her scores on the indicators should increase by amounts proportional to his or her factor loadings. Rightfully questioning the plausibility and logical soundness of this conception, the authors go on to propose replacing the common factor model with systems of structural equations (generally non-recursive, generally non-linear) whose graphical representations allow any two nodes to be adjacent. The authors may object to this characterization, but I do not see how their informal examples ('changes in terms of state' leading adjacent nodes to 'become active') permit a weaker position.

An attempt to elucidate the causal graph containing a set of variables can also raise no objections. But we might question whether this ambitious enterprise is truly in competition with the common factor model. Many writers have found factor analysis to be a powerful tool even though disavowing the causal interpretation of the common factor model that the authors set up as their foil (Lord & Novick, 1968; Messick, 1989; McDonald, 2003; Bartholomew, 2004). In essence, if we wish to measure a psychological attribute such as 'mathematical ability', then we can use the common factor model towards this end without supposing that mathematical ability is a hidden 'lever in the brain'. I suspect that the authors would consider attempts to measure a folk-psychological trait such as mathematical ability to be bad philosophy and worse science. Nevertheless, such attempts make up the daily business of the psychometricians at ETS, ACT, and elsewhere, and I doubt that the target article would dissuade them from engaging in the myriad applications enabled by factor-analytic theory: computing errors of measurement, altering the length of a test to meet a desired reliability, constructing alternate forms, computer adaptive testing, detecting biased items and so forth.

Indeed, longstanding operational tests point to certain domains of personality where factor analysis may be more than merely complementary to the authors' preferred approach. Consider the fact that ETS has written thousands of items for its various tests of aptitude and achievement; two successive administrations of a given test must have no (scored) items in common. Is it sensible to search for the causal graph connecting *all* of the items that have been written for a particular test over the years? This is a deeply puzzling question. It suggests that an abstraction of a potentially infinite set—a common factor—may sometimes be more fundamental than a micro-casual account relating the set members.

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It is noteworthy that my commentary appeals to abilities rather than non-cognitive personality traits. The proffered alternative to the common factor model may seem less attractive in the domain of abilities for at least two reasons. First, ability tests yield data that approach Stout's (1990) ideal of 'essential low-dimensionality' more closely than do personality questionnaires. To the extent that the poor fit of personality questionnaires to low-dimensional factor models provides motivation for a different approach (Vassend & Skrondal, 1997), this motivation is correspondingly reduced in the domain of abilities. Second, a single item in an ability test often seems less psychologically interesting (more exchangeable) than a single item in a scale such as the NEO or the HEXACO. A political scientist might object to treating the item stem 'I get chores done right away' as congeneric with 'I take voting and other duties as a citizen very seriously', because the behaviour probed by the latter may be judged to be important in its own right. Contrast this with the following pair of items:

- If $4x - 5 = 11$, then $3x = ?$
- If the average of four consecutive integers is 18, what is the sum of the least and greatest of the integers?

The necessary judgements here concern what Meehl (1978) called the *situation-taxonomy* and *response class problems*: parsing the raw streams of stimuli and responses into meaningful units. A possible resolution in the domain of non-cognitive personality traits may be to improve the fit of questionnaire data to common factor models through more careful item writing and leaving substantively important individual differences that are either peripheral or 'factorially complex' as nodes to be connected to the personality traits by further investigation.

What exactly is a trait? This is a question that has challenged scientists in all disciplines where it has arisen (Wagner, 2001). The target article's orientation towards single indicators does not dispose of the question—as the authors themselves recognize in their acknowledgment of 'semantically logical dependencies'. If we slightly reword an item stem such as *we can never do too much for the poor and elderly*, it will order the respondents somewhat differently. How should we conceive of the 'error-free' attribute that the stem is intended to measure? It behoves personality psychologists to consider the difficult and essential questions such as this, which lie at the foundation of our field.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 442–443 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1874

Sources of Constraint on Network Equilibrium

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Abstract: We agree with the authors' key point that the standard trait approach to personality does not provide a method for understanding the causal structure of personality. Furthermore, their new technique for visualizing structure shows promise. However, although genetic analyses are important, we think that they are, by themselves, inadequate as a source of information/constraint for understanding causal structure. Close attention must also be paid to the biological systems that they influence, the structure of social situations and the dynamics of the interactions among them. We outline one possible approach to these issues. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: neural network models; connectionism; constraint satisfaction; motivation; motives; personality; traits

The authors make a clear case that the standard trait approach to personality does not provide a causal model for understanding personality and is inadequate for analysing and visualizing personality structure. Their network analysis routines for visualizing the structure of personality measures provide a promising alternative method for analysing and conceptualizing the structure of personality.

Although genetic studies will doubtless inform personality, we see two major issues here. First, the large numbers of different genes likely involved in personality, the combinatorics of the likely gene interactions involved, and the complex dynamics of genetic, biological and environmental factors in predicting emergent traits (Chen et al., 2011) will likely preclude—at least in the short term—using genes to understand the detailed causal structure of personality. Second, even if we could consistently *predict* from genes to trait-item responses, we need conceptual models for the systems responsible for *how* the former actually causes variability in the latter.

Combinations of gene polymorphisms will most likely consistently account for significant individual variability in behaviour (and therefore trait items and traits) when the biological systems (e.g. dopaminergic system components) implicated produce, in combination with environmental factors, differences in broad individual sensitivities (e.g. to internal or environmental cues and experiences). In line with this, recent work by Chen et al. (2011), for example, found that 10 dopaminergic system polymorphisms and their interactions with two environmental factors (parental warmth and life stressors) predicted 15% of the variance in participants' scores on a trait measure of individual sensitivity to external stimuli.

Motivational structures

The paths from an individual's genes to behaviour are complex and are apt to require us to think more systematically and to use modelling tools that provide constraints, capture the dynamics in human personality and person–situation interactions, and bridge from genes to trait-like behaviour. Modelling motivational systems (e.g. approach system associated with the dopaminergic reward pathways) is key.

In a recent neural network model of human personality, Read et al. (2010) argue that personality structure can be understood as arising from the dynamics of structured motivational systems in their interaction with situational affordances. The work by Gray (e.g. Gray & McNaughton, 2000), for example, provides a strong case for two major motivational systems: an approach system, which governs sensitivity to and approach to rewards, and an avoidance system, which governs sensitivity to and avoidance of punishment. Other work on temperament (e.g. Clark & Watson, 1999; Rothbart & Bates, 1998) argues for three major types of biologically based temperament: extraversion, neuroticism and disinhibition/constraint. Extraversion maps onto the approach system and neuroticism onto the avoidance system. Furthermore, disinhibition/constraint is a more general control system that has a general impact on the activation of motives and the control of behaviour (e.g. Clark & Watson, 1999; Rothbart & Bates, 1998). Read et al. (2010) review other work arguing for the universality of a set of underlying specific motives that are nested within the approach and avoidance systems.

Situational affordances and interactions with motivational structures

Different situations provide different affordances for goal pursuit and goal attainment. Moreover, affordances are not randomly distributed across situations. The clustering of affordances in different kinds of situations also puts constraints on the causal structure of personality.

To a large extent, behaviour is a function of the interaction between individuals' motives and the affordances of the situations they encounter, which then cause a particular

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behaviour. Further, individuals' motives strongly influence which situations they encounter and therefore the skills and resources they accrue and their learning histories.

Motivational systems are also shaped in particular ways by experience. A considerable body of research in attachment theory (Cassidy & Shaver, 2008) indicates that there is a relatively limited class of ways in which individuals learn to respond to different patterns of response from their caretakers. One important point here is that the nature of the motivational system constrains individuals' experiences and individuals' responses to them.

These ideas about how we can think of the causal structure of personality have been implemented computationally (Read et al., 2010). A central aspect of this model is that individual motives are arranged in two broad motivational systems: approach and avoidance. Each of the two motivational systems has general parameters that partially determine the behaviour of all the motives within each system. For example, the two systems can independently vary in terms of their sensitivity to inputs, capturing individual variability in approach and avoidance motivations (sensitivity to reward versus sensitivity to punishment). Within each motivational system are specific motives that can also vary in terms of parameters such as their baseline activation or importance and the strength of their connections to situational features (Figure 1).

Behaviour in this network is a joint function of the activated motives, the situational features (that can be modified by experience and define individuals' motivational affordances) and resources that individuals may possess in the current situation, such as money and skills. All three of those components connect with a hidden layer, which learns conjunctions (or interactions) of inputs. Both the influence of situational features on motive activation and the direct impact of situations on behaviour, through the hidden layer, represent two pathways through which the impact of situations can interact with the motives of the individual.

This network is a dynamic system in which behaviour is a function of variations over time in motivational activations and situational affordances. As individuals move between different situations, different motives will be activated, and

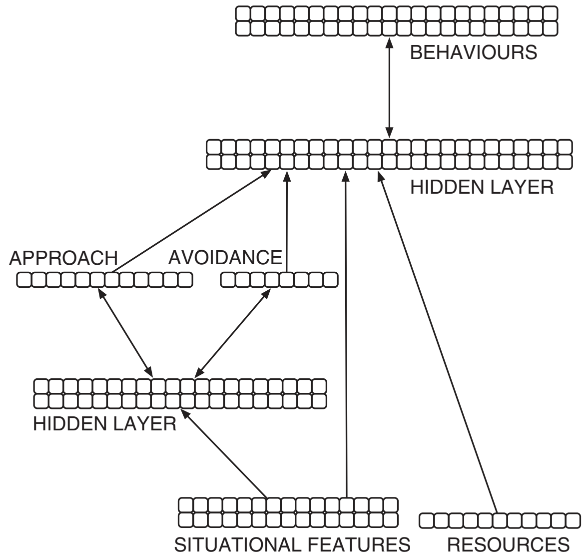

Figure 1. Structure of the Virtual Personalities neural network model. Double-headed arrows represent bidirectional connections between layers. These represent feedback relations among nodes and enable the network to function as a parallel constraint satisfaction network. Single-headed arrows represent unidirectional connections in the direction of the arrow.

different situations will enable the pursuit and attainment of different motives.

CONCLUSION

We concur that we need to rethink the causal structure of personality. Genes will doubtless play an important role in understanding personality structure, especially if we can link them to biological functions involving certain sensitivities and tendencies (e.g. seeking, avoiding and responding to stimuli). Using computational modelling tools can help us understand the complex dynamics of personality systems interacting with situational features in producing the patterns of consistent individual-level behaviours across situations and over time that are the stuff of trait items and trait measures.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 444–445 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1875

Can Network Models Represent Personality Structure and Processes Better than Trait Models Do?

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Abstract: We argue that replacing the trait model with the network model proposed in the target article would be immature for three reasons. (i) If properly specified and grounded in substantive theories, the classic state–trait model provides a flexible framework for the description and explanation of person × situation transactions. (ii) Without additional substantive theories, the network model cannot guide the identification of personality components. (iii) Without assumptions about psychological processes that account for causal links among personality components, the concept of equilibrium has merely descriptive value and lacks explanatory power. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: personality research; person x situation interaction; trait model; network model

We agree that latent variables inferred from patterns of correlated thoughts, feelings and actions cannot serve as causal factors of these very same patterns. Instead, it is necessary to identify psychological mechanisms that generate these patterns and shape behaviour in specific situations. Most importantly, these processes have to be defined independently from the behaviour to be explained. We also acknowledge that time series analyses using repeated ambulatory measures of thoughts, feelings and actions in natural settings may be best suited for identifying person × situation transactions. For three main reasons, however, we are not yet convinced that replacing the trait model with the advocated network model will automatically advance personality theorizing and research. (i) The state–trait model provides a powerful and flexible framework for describing person × situation transactions. Because states can be manipulated experimentally, the state–trait model also has explanatory potential. (ii) Moreover, the proposed network model does not answer the question on how relevant personality components can be identified. (iii) Also, it remains unclear how a state of equilibrium evolves in a mental system.

(1) We disagree with the authors' implicit claim that state–trait models are inferior to network models in capturing person situation transactions. Traits and states can be defined on more than only the domain level, which the authors chose for their critique. The definition of states and traits in the latent state–trait (LST) theory (Steyer, Schmitt, & Eid, 1999) can be applied to all levels of the personality hierarchy including the specific level of personality components such as liking parties. Importantly, LST models can include situation variables that explain state changes. The same is true for all latent growth and true change models (McArdle, 2009). Moreover, substantive theories that combine traits, situations and their interactions can imply nontrivial and even counter-intuitive conditional effects of traits that go far beyond a simple link between a trait and a behaviour (e.g. Perugini, Conner, & O'Gorman, 2011). Finally, states can be manipulated experimentally and thereby assume causal status. Defining traits as average states implies that traits are functionally equivalent to states. Therefore, causal effects of states that were identified experimentally can be generalized to traits (Mathews, 2012; McNiel & Fleeson, 2006).

(2) We argue that the network approach—just like the trait approach—has to be complemented by substantive psychological theories, which allow for the identification of relevant personality components. Importantly, deriving components from the items of personality questionnaires as suggested in the target article may be misleading in several regards. First, personality is more than the self-concept of personality as assessed by self-report questionnaires. Components of personality may function automatically and thus cannot be accessed via introspection. Second, important psychological components might be missing on a questionnaire. To decide which components are relevant for the explanation of specific behaviour, we need theoretical assumptions about how behaviour is formed. Sophisticated trait theories in various domains (e.g. trait anger by Wilkowski & Robinson, 2008; positive affectivity by Grafton, Ang, & MacLeod, 2012) have provided such assumptions by linking personality research to general theories of biological, cognitive, affective and motivational functioning. Sound theoretical grounds are a necessary precondition for the construction of content-valid questionnaires. Third, searching for personality components via heritability analyses of questionnaire items might not be the best strategy. Personality inventories contain items, such as liking parties, that are neither

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culturally nor historically invariant. From an evolutionary point of view, these behaviours are expressions of deeply rooted psychological functions that evolved slowly during our phylogenetic history. Heritability analyses might be better focused on these underlying functions rather than on their malleable expressions. Fourth, it is crucial to distinguish causal from semantic relations between items because only the former are of interest for the explanation of behaviour. For example, being a reliable person semantically implies keeping promises. Finding a close connection between answers to two items with this content does not tell us more than that we share a common language with the subjects.

(3) Using the concept of equilibrium to explain the phenomenon of intra-individual stability in the mental system seems straightforward because the mental system is a prototypical example of a complex system. However, we think that important questions regarding the theoretical merit of the equilibrium concept have not been addressed adequately in the target paper. First, can states of equilibrium evolve without pre-assuming that there are inter-individual differences in initial conditions that are intra-individually stable within the mental system? The authors argue that a state of equilibrium is organized around 'some properties that play key roles in the individual's cognitive and affective economy; i.e., that are important to the person' (p. ?). If persons differ in what is important to them even before states of equilibrium evolve, then it seems reasonable to assume these initial conditions are the causes of the ontogenetic development of personality dispositions. Although this idea is consistent with the traditional trait concept (e.g. Back et al., 2011; Robins, John, & Caspi, 1994), it begs the question of whether states of equilibrium are causes or effects of intra-individual stability in personality. A second question that needs to be addressed is how a state of equilibrium in a personality system comes about. The concept of equilibrium is theoretically independent of the dynamics that are involved in its creation. In other words, the notion of equilibrium does not provide any information about the psychological processes involved in its development. The crucial question regarding this aspect seems to be how the psychological components within the mental system affect each other. The authors argue that the dynamics within the network reflect 'dependencies that may alternatively have causal, homeostatic, or logical sources' (p. ?). In accordance with sophisticated trait theories and consistent with the terminology used in the target article, associative network models, schema models or parallel distributed processing models of memory could be employed that specify principles and consequences of activation and co-activation of components (Read et al., 2010; Rusting, 1998). Without theories about the nature of these causal links among components, it seems premature to refuse the classical trait model.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 446–447 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1876

The Utility of Network Analysis for Personality Psychology

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Abstract: We note that network analysis provides some new opportunities but also has some limitations: (i) network analysis relies on observed measures such as single items or scale scores; (ii) it is a descriptive method and, as such, cannot test causal hypotheses; and (iii) it does not test the influence of outside forces on the network, such as dispositional influences on behaviour. We recommend structural equation modelling as a superior method that overcomes limitations of exploratory factor analysis and network analysis. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: personality; trait; disposition; causality; structural equation modelling; network analysis

Cramer et al. (2012) introduce network analysis (NA) as a new statistical tool for the study of personality that addresses some limitations of exploratory factor analysis (EFA). We concur with the authors that NA provides valuable new opportunities but feel forced by the situational pressure of a 1000 word limit to focus on some potential limitations of NA. We also compare NA to structural equation modelling (SEM) because we agree with the authors that SEM is currently the most powerful statistical method for the testing of competing (causal) theories of personality.

One limitation of EFA and NA is that these methods rely on observed measures to examine relationships between personality constructs. For example, Cramer et al. (2012) apply NA to correlations among ratings of single items. The authors recognize this limitation but do not present an alternative to this suboptimal approach. A major advantage of SEM is that it allows researchers to create measurement models that can remove random and systematic measurement error from observed measures of personality constructs. Measurement models of multimethod data are particularly helpful to separate perception and rater biases from actual personality traits (e.g. Gere & Schimmack, 2011; Schimmack, 2010).

Our second concern is that NA is presented as a statistical tool that can test dynamic process models of personality. Yet, NA is a descriptive method that provides graphical representations of patterns in correlation matrices. Thus, NA is akin to other descriptive methods (e.g. multidimensional scaling, cluster analysis and principal component analysis) that reveal patterns in complex data. These descriptive methods make no assumptions about causality. In contrast, SEM forces researchers to make *a priori* assumptions about causal processes and provides information about the ability of a causal theory to explain the observed pattern of correlations. Thus, we recommend SEM for theory testing and do not think it is appropriate to use NA for this purpose. Specifically, we think it is questionable to make inferences about the Big Five model based on network graphs.

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Cramer et al. (2012) highlight the ability to visualize the centrality of items in a network as a major strength of NA. However, factor loading patterns and communalities in EFA provide similar information. In our opinion, the authors go beyond the statistical method of NA when they propose that activation of central components will increase the chances that neighbouring components will also become more activated. This assumption is problematic for several reasons. First, it is not clear what the authors mean by the notion of activation of personality components. Second, the connections in a network graph are not causal paths. An item could be central because it is influenced by many personality components (e.g. life satisfaction is influenced by neuroticism, extraversion, agreeableness and conscientiousness) or because it is the cause of neighbouring items (life satisfaction influences neuroticism, extraversion, agreeableness and conscientiousness). Researchers interested in testing causal relationships should collect data that are informative about causality (e.g. twin data) and use SEM to test whether the data favour one causal theory over another.

We are also concerned about the suggestion of Cramer et al. (2012) that NA provides an alternative account of classic personality constructs such as extraversion and neuroticism. It is important to make clear that this alternative view challenges the core assumption of many personality theories that behaviour is influenced by personality dispositions. That is, whereas the conception of neuroticism as a personality trait assumes that neuroticism has causal force (Funder, 1991), the conceptualization of neuroticism as a personality component implies that it does not have causal force. The authors compare personality constructs such as neuroticism with the concept of a flock. The term *flock* in the expression *a flock of birds* does not refer to an independent entity that exists apart from the individual birds, and it makes no sense to attribute the gathering of birds to the causal effect of flocking (the birds are gathered in the same place because they are a flock of birds).

We prefer to compare neuroticism with the causal force of seasonal changes that make individual birds flock together to fly south or north. A major limitation of NA is that it does not allow for unobserved causal forces to influence behaviour. Staying with the analogy, by mapping the relationships among birds, NA lacks a tool for modelling the influence of causal factors that influence all birds, such as the seasonal changes. Similarly, studies of intra-individual variation in behaviour over time cannot reveal the influence of personality traits that produce stable and consistent differences between individuals. One advantage of SEM is that it is possible to test causal models of within-person and between-person variances and to examine whether stable dispositions contribute to between-subject variance (Kenny & Zautra, 1995; Schimmack & Lucas, 2010).

We think that personality psychology has resurged as an important discipline in psychology because ample evidence demonstrates that human beings are not blank slates who are temporarily programmed by reinforcement schedules. Rather, human beings have unique personalities that have persistent effects on their experiences, goals and behaviours. The main weakness of NA is that it lacks the capability to investigate the contribution of personality traits to human diversity in behaviour and experiences. As such, NA constrains personality researchers as much as EFA. The main advantage of SEM is that it does not force researchers to make assumptions that are dictated by the statistical model. Rather, personality researchers can use SEM to test competing causal theories. Most likely, observed behaviours are the product of a complex interaction between personality traits and environmental factors that are mediated by cognitions, motives and affective responses. A major challenge for psychologists remains the measurement of these mediating processes. At present, latent variable models of multimethod data provide the best opportunity to meet this challenge.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 447–448 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1877

Does Network Theory Contradict Trait Theory?

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Abstract: I argue that the trait and network theories of personality are not necessarily contradictory. If appropriately formalized, it may turn out that network theory incorporates traits as part of the theory. I object the opinion that if a trait is a cause of behaviour, then it is necessarily an entity operating in the minds of individuals. Finally, I argue that liking parties can be a label for a random variable (item), a stochastic process (a family of items at different time points) and a latent variable (trait). In our colloquial language, we do not make these distinctions, which leads often to confusions. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: network theory; trait theory; latent state-trait theory

Let me start saying that I do welcome this paper; I think it may start a new research paradigm in personality. It is another instance illustrating the fact that what is seen and held true depends on the concepts used to look at the world. Conceptual systems are like glasses that make some things visible, and at the same time, they conceal others. Obviously, this does not mean that the other things are not there. Changing glasses makes them visible again. Clearly, which glasses we should use depends on our aims. What do we want to see? What do we want to study? What do we want to explain?

From my point of view, the conceptual system used by the authors, let us call it *network theory* (NT), does not contradict trait theory (TT). Therefore, I do not share the authors' opinion expressed most clearly when they asked: 'do traits cause cognitive, affective and behavioral components or do traits emerge from complex interactions between these components?' Obviously, the authors believe that only one of these alternatives can be true, and here I object. I think that many theories are seemingly incompatible only because they lack a sufficient degree of adequate formalization. Of course, this does not only apply to NT but to most psychological theories.

However, there are exceptions. Consider, for example, latent state–trait theory (LSTT; Steyer, Ferring, & Schmitt, 1992; Steyer, Schmitt, & Eid, 1999; Steyer, Geiser, & Fiege, 2012). Although this theory is still simple, it shows that the concepts *traits*, *states*, *persons*, *situations* and *person–situation interaction* can coexist in the same theory. Moreover, within this theory, the concept of a latent state contributes to a deeper understanding of a latent trait and vice versa.

The construction of traits in LSTT also shows that they do not 'operate in the minds of individuals', as Cramer et al. suggested. Instead, from my point of view, they operate in our minds if we adopt the theory. They are our constructions that help us understand certain empirical phenomena. There is no need for a 'reification of factors like extraversion as causes of individual behavior' even if we consider them causes of behaviour with important empirical implications (see my comment on Lee, 2012).

For simplicity, let me illustrate this point not by extraversion or general intelligence (g) but by the trait h pertaining to coins: the inclination to show *heads* if flipped. Suppose I have a set of coins $u = 1, 2, \ldots, N$, each being treated in the course of its life with a number of instruments resulting in different shapes and forms. In fact, some are convex, more like little woks, some are S-shaped, while others still have an even shape. When flipping many of these coins again and again, the observation is that they significantly differ in their relative frequencies to show *heads*. Obviously, there are true inter-individual differences between the probabilities $p(u)$ to show heads. Now, I introduce a latent trait h as a logistic transformation of the probability p of a coin to show *heads*. The model is similar to the Rasch model but without difficulty parameters. Drawing a sample, each coin is flipped 30 times so that I have 30 items Y_{ij}, $j = 1, 2, \ldots, 30$, for each of the coins $i = 1, 2, \ldots, n$ to be drawn. (Let us call this *random experiment A*. Note that i is the coin to be drawn at the ith repetition of drawing a coin, whereas u denotes a specific coin in the set mentioned above.) The analysis will show perfect model fit and will yield estimates of the h scores of the coins.

The point I would like to make is that neither $p(u)$ nor its logistic transformation $h(u)$ is in coin u; the coins just have certain shapes. Instead, I constructed a concept, the trait h, that perfectly explains the behaviour of these coins in a *random experiment B* of drawing a single coin from a set of coins and flipping it and, of course, also in a *random experiment C* of flipping the specific coin u. These are the empirical phenomena h theory refer to and for which it is needed, for example, if I use such a coin playing for money with someone else.

The limitations of h theory are obvious. Of course, life shaped these coins differently so that they have different physical properties, and h theory does not explain *why* the

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coins have developed this way, nor does it explain how *h* is related to the degree of convexity and to other physical properties of the coins. However, it does give an explanation for their different behaviour, and it will never contradict other correct theories that might answer questions such as those raised above.

The items Y_{it} in the outline of *h* theory refer to *random variables* in random experiment A. Hence, *h* itself refers to a random experiment, and it may be useful in similar random experiments. The item is not 'the coin shows *heads*'. This may be an appropriate *label* of the item. Instead, the item is a random variable and so is *h*. Random variables have certain structural or formal properties; for example, they can correlate. In contrast, labels are just names. A label may invoke more meaning than it should.

Now, let us consider passages such as 'liking parties is a personality component…'. What do we talk about? To me it sounds like a reification of an item, which, in my mind, is inappropriate in the same way as the reification of the trait *h*. The item *liking parties* may be caused by *extraversion* if both labels refer to random variables, say *Y* and *e*, respectively, both of which are constructed in a similar way as described above in *h* theory. *Liking parties* may also be a label for a stochastic process $(Y_t)_{t \in T}$. In this case, *liking parties at time t*, that is, the random variable Y_t, may depend, even in a causal sense, on another variable Y_s, $s < t$, in the process or in another process running simultaneously (such as in a multiple time series). *Liking parties* may also be a label for a trait. In this case, it is considered to be a specific property of a person, just like *e* and *g*. Thus, we have already three meanings of *liking parties*, and I am looking forward to future papers making the necessary distinctions between the core concepts of the theory. When this process of clarification has reached a satisfactory state, we will be able to see if NT will incorporate TT, just like LSTT incorporates traits and states, as well as persons, situations and their interaction in a single coherent theory. But admittedly, working this out for NT is a formidable challenge.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 449–450 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1878

Why Do (Some) Birds Flock? Causality and the Structure of Characteristic Adaptations

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Abstract: Characteristic adaptations often cluster in mutually reinforcing networks. Evidence of stability and heritability suggests that the development of such networks is due in part to the causal influence of enduring dispositions or traits. Many different genetic models are consistent with this hypothesis, and the quest for genes can be pursued at many levels; of these, the intermediate level of specific facets may be the most promising. Published 2012. This article is a U. S. Government work and is in the public domain in the USA.

Key words: personality; facets; genetics; stability; causality

In their discussion of causality, Cramer and colleagues present the instructive example of flocking birds: the behaviour of the flock is not guided by an invisible leader but emerges from the responses of each bird to the behaviour of others in its environment. Those behaviours can be said to be mutual causes of each other. But surely that is not the whole story; otherwise, we would expect all bird species to flock, which is clearly not the case. Presumably some species flock because they have evolved a mechanism, or suite of mechanisms, that allow each bird to respond to its environment in ways that give rise to flocking behaviour. Loosely, we can call this set of mechanisms a *flocking instinct*, present in some species but not in others. Surely it is meaningful to say that the innate flocking instinct is *a cause* of flocking behaviour, because when it is absent, flocking does not occur. Causality is multilayered; thus, it is perfectly reasonable to say that party going is caused (proximally) by liking people and that it is caused (distally) by extraversion. Readers interested in on trait explanations can consult McCrae and Costa (1995, 2008a).

In support of their claim that extraversion cannot be a real cause of party going, Cramer and colleagues cite a factor analysis of NEO-PI-R items that failed to find that item covariance is fully accounted for by five factors. This is an unfortunate example, because the NEO-PI-R test authors have always claimed (with supporting evidence) that its items assess at least 30 distinct traits (Jang, McCrae, Angleitner, Riemann, & Livesley, 1998; McCrae & Costa, 1992). A more appropriate analysis, modelling 30 facets that are themselves related to one or more of the five higher-order factors, would probably show better fit. But ultimately, no model fit statistic is either necessary or sufficient to establish the viability of the hypothesis that personality factors are (distal) causes of behaviour. Scientific hypotheses, including causal hypotheses, must be evaluated on the basis of a broad pattern of evidence, thoughtfully interpreted.

Cramer and colleagues focus on fairly specific components of personality represented by personality questionnaire items. From the perspective of Five-Factor Theory (FFT; McCrae & Costa, 2008b), these components would be considered *characteristic adaptations* (beliefs, habits, interests and so on) that emerge from the interactions of underlying traits (basic tendencies) and life experience; the connections between the components are called *dynamic processes*. FFT acknowledges that characteristic adaptations themselves interact in ways that might be described as a network. Consider, for example, this description of the life of a hypothetical individual high in neuroticism.

> In social situations he is anxious and embarrassed, and his frustration in dealing with others may make him hostile, further complicating matters. In compensation he turns to the use of alcohol or food, and the long term results are likely to be depressing. Although the emotions and impulses that disturb him may not occur simultaneously, they succeed one another with distressing regularity. (McCrae & Costa, 1984, p. 43)

Cramer and colleagues argue that neuroticism itself is nothing more than a description of such a network of actions and reactions. That is certainly one hypothesis, but it does not seem to account for the facts of stability and heritability. One might plausibly argue that individuals settle into certain self-perpetuating patterns of characteristic adaptations that we could describe as high or low levels of a trait. But if this were the whole story, then the trait level would be arbitrary and rather easily changed by traumatic events or interventions that tip the pattern into a new equilibrium. We might, for example, teach the unfortunate individual described earlier to be more comfortable around others and expect that in consequence he would become less hostile and cheerier in attitude. In practice, such transformations are difficult to achieve (Ellis, 1987). Similarly, we might expect that identical twins separated at birth would experience different pathways of development

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and show no particular personality resemblance as adults, but this is not the case (Tellegen et al., 1988). From such facts, we infer that neuroticism and other traits are biologically based mechanisms, or suites of mechanisms, that guide the development of characteristic adaptations just as the flocking instinct guides the behaviour of birds.

Cramer and colleagues acknowledge that traits have genetic bases, and they offer two scenarios. In one, all genes affect a single factor, which affects personality components; in the other, different genes affect different components and their connections. However, FFT would consider *both* of these simplified models—or a combination of them—to be consistent with the idea that trait factors reflect a suite of biologically based mechanisms that influence dynamic processes (Postulate 6b) and guide the development of clusters of characteristic adaptations (Postulate 2a; McCrae & Costa, 2008b).

Consistent with this broader conception of causality, we have conducted genome-wide association studies not only of broad factors (Terracciano, Sanna, et al., 2010; de Moor et al., 2012) but also of more narrowly defined facets, such as the excitement-seeking component of extraversion or the depression component of neuroticism (Terracciano, Tanaka, et al., 2010, Terracciano et al., 2011). We have argued for the value of investigating the genetic basis of personality constructs less heterogeneous than broad factors (Terracciano, Tanaka, et al., 2010; Jang et al., 1998), just as we believe that research that includes personality facets can provide a more granular understanding of the relationships with behaviours and important life outcomes (Terracciano et al., 2009; Sutin et al., 2010; Paunonen, Haddock, Forsterling, & Keinonen, 2003).

The position of Cramer and colleagues stands at the extreme of the bandwidth-fidelity debate. Their proposal of analyses at the level of single items raises a number of empirical and conceptual concerns, including the unreliability of single items, the proliferation of statistical tests, reduced comparability of results across studies that use different questionnaires, and the limited generalizability of findings. Facet-level analyses seem to offer a promising compromise between overly broad and excessively narrow phenotypes.

DOI: 10.1002/per

European Journal of Personality, *Eur. J. Pers.* **26**: 451–459 (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/per.1879

Author's Response

Measurable Like Temperature or Mereological Like Flocking? On the Nature of Personality Traits

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Abstract: Some commentators wholeheartedly disagreed with the central tenet of the network perspective on personality, namely that traits are the result of mutual interactions between thoughts, feelings and behaviours. In this rejoinder, we primarily focus on these commentaries by (i) clarifying the main differences between the latent versus the network view on traits; (ii) discussing some of the arguments in favour of the latent trait views that were put forward by these commentators; and by (iii) comparing the capacity of both views to explain thoughts, feelings and behaviours. Some commentators were by and large positive about the network perspective, and we discuss their excellent suggestions for defining components and linking these to genes and other biological mechanisms. We conclude that no doors should be closed in the study of personality and that, as such, alternative theories such as the network perspective should be welcomed, formalised and tested. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: latent trait perspective; personality traits; network models

'No doors should be closed in the study of personality'.
(Allport, 1946)

What are traits? To this question, there are almost as many answers as there are personality psychologists. Our target article was a first attempt at formulating a novel *theory* of personality (and not, as **Schimmack and Gere** suggest, merely a new analysis tool) in which traits do have a place. The difference with existing perspectives is that we do not see traits as *causes* of thoughts, feelings and behaviours (i.e. personality components)—the idea that has come to dominate personality psychology in the past decades—but as *consequences* of the interactions between such thoughts, feelings and behaviours. Thus, rather than reflective latent variables, personality traits are better conceived of as formative variables: summaries of relevant cognitive, affective and behavioural components that interact with one another in myriads of ways. We hypothesised that clusters of more strongly correlated components, typically interpreted as *signs* of underlying factors, in fact signal components that are particularly strongly interconnected. The coordinated behaviour of these components thus *emerges* from the local interactions between them, just like flocking emerges from the local interactions between birds.

The commentaries we received are dividable in two general response categories: the first contains commentaries that were by and large positive, including very helpful suggestions for improving the precision and scope of the network perspective (**Costantini & Perugini; Denissen, Wood & Penke; Furr, Fleeson, Anderson & Arnold; Read & Miller**). The second class consists of commentaries that were (sometimes wholeheartedly) dismissive of our proposal, mainly because of reluctance to let go of the idea that personality traits *necessarily* are latent entities (e.g. **Guillaume-Hanes, Morse & Funder; Schimmack & Gere; Terracciano & McCrae**). The primary focus of this rejoinder pertains to this latter collection of commentaries. More specifically, we aim at (i) clarifying the main differences between the latent versus the network view on traits; (ii) discussing some of the arguments in favour of the latent trait view that were put forward by commentators; and (iii) comparing the capacity of both the network view and the latent trait view to explain thoughts, feelings and behaviours. Finally, we discuss some of the commentators' excellent suggestions for defining components and linking these to genes and other biological mechanisms.

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TEMPERATURE VERSUS FLOCKING

Why do some aspects of personality, such as party-going behaviour and liking people, cluster together? In the latent trait view, they do so because they are *caused* by the same underlying trait (extraversion in this example). This definition of a personality trait, as a cause of behaviours, thoughts and feelings, has come to permeate the field of personality psychology under many different names (source traits: Cattell, 1950; genotypic traits: Eysenck, 1967; trait$_2$: Wiggins, 1984) and is mathematically formalised in the generic latent variable model. In such a latent variable model, a personality trait and its items are associated with one another analogously to the relation between temperature and thermometers (see also Borsboom, 2008): differences in temperature cause differences on thermometer readings via a well understood process by which particles exchange kinetic energy. If multiple thermometers are used (in the personality case: extraversion causes party-going behaviour and liking people), thermometer readings are *measurements* of a common latent variable, namely temperature (extraversion is measured by items such as party-going behaviour and liking people).

The hypothesised measurement relation between a trait and its items features prominently in the five-factor theory of personality, most vehemently advocated by **Terracciano and McCrae**. Importantly, this and comparable factor models come with the assumption of *local independence* (Holland & Rosenbaum, 1986; Lord, 1953; McDonald, 1981): in the temperature analogy, a high correlation between the readings of two thermometers at the same time can be (almost perfectly, depending on the reliability of both thermometers) explained by the underlying cause of these readings, namely temperature. That is, if differences in temperature function as the *common cause* of differences in the thermometer readings, then there can be no direct relation between the two thermometers (i.e. changing the reading on one thermometer does not cause a change in the reading on the other thermometer and vice versa). In a measurement model, this is a highly sensible requirement. However, in our view, it is not a very plausible model for the relation between, say, conscientiousness and being in time for appointments.

This neither implies that factor models are useless nor that the results of factor analysis and related techniques cannot be reinterpreted along different lines. As such, **Ashton and Lee** are free to advocate their own non-causal definition of a factor as 'a common element shared by its defining variables' (e.g. all birds have feathers), and we agree with **Ashton and Lee** that non-causal interpretations of factors are compatible with a network perspective. For pragmatic reasons, it may also be useful to aggregate co-varying individual differences into larger components and neglect the more stringent assumptions of factor analysis. However, we do not see how the assumptions of factor analysis sit with the idea that factors can be identified with *common elements*. The factor model does not hypothesise that there is a common element among indicators but that they share variance; moreover, that they share variance for a very special reason, that is, because they depend on the same latent variable. And *this* is what the psychometric model *is* consistent with, as the latent variable functions precisely as an unobserved common cause (e.g. having feathers is what causes certain animals to be birds; Pearl, 2000).

When adhering to a latent variable model-based explanation of the clustering of certain items, one cannot evade the local independence assumption: although it is technically not a problem to fit a one-factor model in which certain items are allowed to correlate, in addition to and independent of the relation that they share via the latent factor (i.e. to have a *direct* relation, a weaker form of the above-mentioned strict local independence assumption), the more such correlations are allowed to exist in the model, the less convincing is the case for an underlying trait that explains the majority of covariance between the items. Thus, when **Terracciano and McCrae** argue, in *defence* of the latent trait view, that liking parties is caused by both liking people and extraversion, they actually shoot themselves in the foot by admitting the existence of *direct* relations between the items of extraversion. If direct relations are allowed, factor analysis ceases to be a credible tool for identifying unobserved causes because that interpretation is crucially dependent on the assumption of local independence.

Naturally, other ways of tweaking this basic model of temperature are possible, and we acknowledge (again) that we fitted the simple model without distinguishing between first-order and second-order factors (e.g. **Ashton & Lee; Terracciano & McCrae**). However, **Terracciano and McCrae** are not committed to these more complex models either when they maintain their position that extraversion causes party-going: there is no distinction between first-order and second-order factors in this statement. Certainly, one may fit a much more complex model to the data with cross-loadings and *lower order* latent causes. However, in our view, this implies that to meet the assumption of local independence, one then introduces many extra, untested hypotheses. The alternative is to drop the unlikely assumption of local independence. As shown by van der Maas and colleagues, a network of interdependent components can provide a valid alternative for a well-fitting complex factor model. We stress that, in practice, factor analysis merely identifies clusters of items that correlate more highly with one other than with items outside the cluster. Hence, items that *load on the same factor* may be taken to identify networks of mutually reinforcing components (see van der Maas et al., 2006). In that case, a factor is not a latent trait with causal power but a summary statistic for how a set of items are influenced by one another (see Cramer, 2012). This idea resembles Tellegen's (1991, pp. 15) assertion that 'A trait dimension is . . . a population concept representing an orderly statistical structure of covariation', as well as Mischel's (1973) thesis that traits are 'summary terms. . .applied to observed behavior'.

Pertaining to the network perspective, some commentators were under the impression that we dismiss traits or that we equate traits to a single item (e.g. **Asendorpf**). We do not. **Steyer** is absolutely right when postulating that trait theory and the network perspective are not incompatible. That is, if one is willing to let go of the idea that a personality

DOI: 10.1002/per

trait necessarily is a *latent cause* of thoughts, feelings and behaviours, then traits and the network perspective are perfectly fit for marriage. We may have added to the confusion by discussing individual personality components in which we endowed them with state-like or trait-like properties. Importantly, we do not hypothesise that single components/items are traits; we did want to argue that personality components can be stable (i.e. trait-like) as well as being subject to change (i.e. state-like). In that respect, there is indeed some overlap between the network perspective and the latent state-trait model, as was noticed by several commentators (**Costantini & Perugini; Rothmund, Baumert & Schmitt; Steyer**). However, contrary to the network perspective, the latent state-trait model is a *temperature* model in which individual items are caused by a latent state variable, which is, in turn, partially caused by a latent trait variable. In this respect, it is useful to distinguish between factor analysis as a pragmatic tool to organise data and the results of factor analysis as a model to explain data. Although it is unlikely that factor analysis of personality items would result in a credible explanatory model, this does not imply that it cannot be a useful statistical tool. As such, although we think the explanatory power of the latent state-trait model is limited, we acknowledge its usefulness as a statistical tool that can help in determining which personality components exhibit more state-like properties compared with others.

In the network perspective on personality, there is ample space for traits such as extraversion and neuroticism, if these are interpreted as clusters of mutually reinforcing components. The main difference with current trait theories is that from this perspective, traits do not function analogous to temperature nor do the items function analogous to thermometers. Instead, we postulate that the constellations of components that we designate as signs of underlying traits in fact result from the direct, local interactions between personality components. These may or may not be equated to single items (a subject we will return to in the final paragraphs of this rejoinder). We used the flocking behaviour of birds as an analogy, which needs, given some of the comments, some additional clarification. It is important to stress here that we did not invent the idea that birds, and other species, display flocking behaviour because of local rules. Many simulation studies have confirmed that from a set of simple rules–for example, steer towards average heading of neighbouring birds–a complex flocking pattern (e.g. a V-shape) can occur (e.g. Hartman & Benes, 2006). Thus, there is no underlying flocking instinct (**Terracciano & McCrae**) or a latent *seasonal change* variable (**Schimmack & Gere**) that explains the flocking behaviour of birds. **Schimmack and Gere** are right when they stress, in defence of the latent trait view, that flocking behaviour is not '. . .an independent entity that exists apart from the individual birds. . .' but that is exactly the point: in our view, that applies to personality traits as well. That is, extraversion is not an independent entity that exists apart from the individual extraversion components: instead, just as flocking, personality traits *emerge* out of the interactions between personality components. As such, from a network perspective, the relationship between a trait and its components is not one of measurement but one of *mereology*: that is, extraversion components do not measure extraversion; the interactions between these components are what constitute extraversion.

What does this mean? For one, extraversion and other personality traits cannot be understood by meticulously studying the inner workings of a single personality component. We think that virtually all commentators would agree with this: we cannot, for example, understand neuroticism by discovering all there is to know about a single component such as feeling jittery. However, that is what the latent trait, temperature, model, implies: most of what we know about temperature (what it is and how it is related to thermometers) can be discovered by precisely investigating how it is related to one particular thermometer (a mercury thermometer for example).

THE PRAGMATIC, BIOLOGICAL PLACEHOLDER: DEFENDING THE LATENT TRAIT VIEW

In defence of the latent trait view, some commentators deny the reification of latent traits. That is, they adhere to a factor model-based temperature view of personality traits but claim to refrain from endowing the latent variables with any realist connotation. When having a temperature model in mind and when philosophising about the nature of personality traits, is it unavoidable to reify the latent variable (see also **Wilt, Condon, Brown-Riddell & Revelle**)? In principle, no. From a *pragmatic* point of view, it is possible—as **Lee** points out in the case of mathematical ability—to work with latent variable models without believing that the latent factor has a material referent. However, the moment one searches for biological determinants that correlate with the latent variable, or for heritability of the latent variable, one wades into the murky waters of reifying the latent variable at least to some degree. Although not explicitly—the majority of commentators would likely refrain from endorsing the statement that neuroticism resides in a particular structure in the brains of individual people—many personality psychologists implicitly reify the latent variable when claiming that neuroticism is highly heritable or that gene X is associated with being extraverted. For what would be the use of searching for genetic determinants of something one does not believe to exist in some shape or form? One cannot pinpoint the *location* of temperature either, yet climatologists who claim that a permanent increase in average temperature is associated with an upslope tree line shift do believe that temperature is a real and causal phenomenon, although they cannot directly observe or touch it. As such, although we agree with **Steyer** that strong reification of the latent variable of the sort that personality traits are believed to be in the minds of individual people might not be what the vast majority of personality psychologists think *when asked* (although Allport and his followers do commit to the hypothesis that traits are real, that they exist *in our skins*; Allport, 1968, pp. 49; Funder, 1991), when correlating latent variables (by their sum score proxy) with all sorts of (non-) biological phenomena and by engaging in statements such as 'women are more extraverted than men'; however

DOI: 10.1002/per

(see also Kievit et al., 2011), they do grant the latent variable a status that comes undeniably close to reification.

In fact, that quest for biological and/or genetic mechanisms is often fueled by the desire to endow the latent variable with some realist connotation. In this vein, **Terracciano and McCrae** defend the latent trait view with an argument along the following lines: personality traits are heritable, they are thus biologically based mechanisms; and because they are biologically based, personality traits exist. First, it is misguided to use heritability as evidence for the hypothesis that some aspect of human functioning is reducible to *specific* underlying biological processes. Turkheimer (1998) contrasts the silence of an ascetic monk and an aphasic individual as an example: both religiosity and aphasia are heritable traits, but everyone will agree that in the case of the monk, his/her silence, which is a *symptom* of his/her religiosity, is not due to specific brain structures or processes (e.g. *religious silence is caused by a lesion in Brodmann area's 16 and 24*), whereas in the case of an individual with, say, Broca's aphasia, we know that his/her silence is caused by a lesion in Broca's area. Thus, the fact that neuroticism is heritable does not imply that neuroticism is reducible to/associated with specific biological mechanisms. Second, the more *general* statement that personality traits are biologically based mechanisms without implicating any specific structure or process is utterly uninformative. Ultimately, all behaviour is biologically caused in some sense (i.e. the result of biological processes), and as such, biological reductionism of mental phenomena such as personality traits is pointless unless one would want to maintain the hypothesis that certain behaviours, thoughts and/or feelings are not ultimately grounded in the brain of the individual who experiences or displays them (see also Greenberg & Bailey, 1993; Kendler, 2005).

For some commentators, it is not so much the supposed *biological reality* of personality traits that prompts them to defend the latent trait view. Rather, in what we call the *placeholder* argument, personality traits cannot be something other than latent variables because that is the only way to understand why certain behaviours/thoughts/feelings (i) are present in some but not all humans (**Terracciano & McCrae**); and (ii) that do not appear to be causally related but are correlated (**Guillaume-Hanes, Morse & Funder**). In this view, the latent variable functions as a placeholder for everything we do not (yet) understand (i.e. latent variable as an *unknown* phenomenon), which is notably different from the interpretation of the latent variable as it figures in measurement and structural models (viz, as an *unobserved* phenomenon). What is wrong with the placeholder argument? For example, **Terracciano and McCrae** argue that because some birds display flocking behaviour whereas others do not; it *must* be so that an underlying *flocking instinct* exists that causes these behavioural differences between bird species. Let us translate this hypothesis into an example that pertains to humans: some women prefer high heels whereas others do not; thus, it must be so that an underlying *instinct to wear high heels* exists that causes these behavioural differences between women. This obviously makes no sense. Although it may well be that we do not (fully) understand why it is that some women prefer high heels whereas others do not, the reasons we can think of do not justify the need for an underlying instinct: high heels are not practical in certain jobs, some women wear high heels to look taller, high heels cause back problems in some women, etc. Naturally, there are examples where the latent placeholder would be more defensible, but the thesis that behavioural differences *necessitate* the existence of an underlying instinct/tendency is, in our opinion, highly questionable.

Now, suppose we would find a positive correlation between wearing high heels and working on the top floor of a skyscraper. According to **Guillaume-Hanes, Morse and Funder**, this correlation can only be understood by introducing an underlying tendency, in this example something such as *elevation tendency*, because there is no sensible way in which one can justify a direct relation between the two behaviours. The latter part of this argument is true. Likewise, in their own example, it is virtually impossible that ice cream eating causes children to seek their teacher's approval as well as the other way around. Besides methodological reasons why ordinary correlations do not necessarily imply a true relation between two variables (e.g. large sample size that causes low correlations to become significant, partial correlation might reveal that correlation is caused by a third (non-latent) party, etc.), **Guilllaume-Hanes et al.** ignore another reason why two seemingly wildly removed phenomena are correlated, which does not involve latent entities: for example, most women who work on the top floors of skyscrapers take the elevator. And because they take the elevator, they are not bothered by the discomfort of wearing high heels when climbing stairs. As a result, these women more readily wear high heels than women who take the stairs to reach their lower floor offices or the other way around: some women in highly successful companies with predominantly male employees like to accentuate their femininity by wearing high heels. And successful companies often occupy the most expensive floors in skyscrapers, the top floors. As such, at the inter-individual level, two behaviours can be related through a *causal chain* that involves directly observable, non-latent variables.

NOT AS STRAIGHT AS AN ARROW: THE REAL TROUBLE FOR THE LATENT TRAIT VIEW

Interestingly, the potentially most compelling argument in defence of the latent trait view was not once articulated by any of the commentators. That argument would have been that it is known how latent traits influence behaviours, thoughts and feelings; that is, that we know what the *arrows* in the measurement model signify. Consider again the analogy with temperature: we know exactly what the arrow between temperature and a measurement with a mercury thermometer means, namely, that an increase in ambient temperature results in an increase in the temperature of the mercury causing (in a linear fashion) the mercury in the glass tube to expand. For personality traits, however, it is no surprise that this argument was not articulated because no one really knows how, say, neuroticism causes *feeling jittery* and *worries easily*. As Mischel and Shoda stated (1994), if

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traits generate distinctive behaviour, then evidence for this claim needs '...to be stated explicitly and announced clearly'. Yet, to the best of our knowledge, this evidence is not unannounced, it simply is not there. Naturally, there are theories of how traits and behaviour are linked, for example, the trait theory as postulated in McCrae and Costa (1995). However, the meaning of the arrows in their model is shrouded in mystery: they are not really discussed nor empirically verified and are endowed in the model with the vague label *dynamical processes*. So, when **Rothmund, Baumert and Schmitt** state that '...without theories about the nature of these causal links among components, it seems premature to refuse the classical trait models', they forget that for these very classical trait models, not one empirically verified theoretical model about the causal links between traits and concrete behaviours exists.

Thus, as Pervin (1994) rightly pointed out, personality traits are regarded as explanatory concepts, yet '...explanations are not offered in other than trait terms', resulting in circular arguments such as extraversion causes party-going; John likes to go to parties because he is extraverted. Why is it that trait theorists have not searched for how personality traits exert their supposed causal powers onto lower level behaviours, thoughts and feelings? There are probably many reasons—beyond the scope of the present rejoinder to discuss—but one reason might have to do with the manipulability of the supposed latent traits. An important way of investigating the explanatory power of a theory is to manipulate the hypothesised cause of a certain phenomenon X after which one assesses the impact of that manipulation on X. One problem with personality traits, besides the obvious ethical constraints on such a research design, is that to manipulate a trait, one has to have a fairly good idea of what a trait is. And, although regarded as a *human universal* (McCrae & Costa, 1997), we have already argued in earlier paragraphs that in current trait theory, there is no validated hypothesis on the nature of personality traits. Also, trait theorists themselves strongly argue in favour of the stability of these traits (Terracciano, Costa, & McCrae, 2006). That is, especially after age 30, personality traits are supposedly relatively stable and thus relatively insensitive to external manipulation (if possible at all). On a final note, when reviewing the literature, it also seems that trait theorists are generally not very interested in answering the question of how traits cause behaviour. In fact, McCrae and Costa (1995), for example, consider the causal link between traits and behaviour as self-evident and, as such, seem to obviate any need for formulating and testing explicit hypotheses about this link:

> '..., the causal argument is in principle clear: traits as underlying tendencies cause and thus explain (in general and in part) the consistent pattern of thoughts, feelings, and actions that one sees. This kind of argument is so consistent with philosophical construals of disposition (...), with the theories of psychologists from Allport to Eysenck, with the assumptions underlying classical psychometrics, and with common sense that it is hard to understand why it should be problematic'.

In our view, future research into the network perspective on personality should commit itself to the systematic identification and analysis of causal links between personality components at both the inter-individual and intra-individual levels. In our target paper, as **Asendorpf** rightly notes, we have only scratched the surface of the many possible interactions between personality components and how one can go about in analysing possible causal mechanisms. For some relations at the inter-individual level, the causal mechanism probably operates at a more psychological level (those examples were most frequently discussed in our target paper): in general, liking to meet new people causes some individuals to seek out events where new people can be met, and therefore, these individuals frequent parties. And in these cases, there is no need for reducing this mechanism to a more *biological* explanation (e.g. neuron group X firing in region A causes neuron group Y in region B to fire). In other cases, biological mechanisms will be more important (e.g. in psychopathology and how not sleeping causes fatigue). And in these cases, we welcome the suggestions of **Read and Miller and Wilt, Condon, Brown-Riddell and Revelle** for how to incorporate biological mechanisms into the network model, for example, by positioning such mechanisms between genes and personality components.

Between-subject generalisations do not necessarily correspond to causal mechanisms that characterise within-person functioning. As **Furr, Fleeson, Anderson and Arnold** show in the case of borderline personality disorder, causal mechanisms for developing the disorder might be very different for two people with the same diagnosis. Pertaining to normal personality, it might well be, for example, that in general, party-going behaviour is predominantly caused by liking to meet new people, but that John likes to go to parties because he wants to be the centre of attention and that Chris frequents parties because he wants to raise money for his next film (**Asendorpf**). So, when **Asendorpf** criticises the network perspective by arguing that people might vary in the causes of their party-going behaviour, he inadvertently mentions a phenomenon (i.e. intra-individual differences in why certain behaviour is present) that flows naturally from the basic premises of the network theory. In the network theory, the personality networks of John and Chris can be structured entirely different with the same end result: both men are extraverted. In John's case, his party-going behaviour is caused by another personality component, wanting to be in the centre of attention; in Chris' network, his party-going behaviour is caused by an external event (an upcoming film). Thus, there may be as many sources of *extraversion* as there are events that cause people to like parties or lead them to make friends easily. Importantly, this is not readily explainable by the latent trait, temperature, view. For in this view, personality traits cause behaviour in the same way in every individual, just as temperature causes a reading on a mercury thermometer in exactly the same way regardless of whether the temperature is measured in the Himalaya Mountains or in someone's backyard.

DOI: 10.1002/per

THE PIECES THAT MAKE UP THE PERSONALITY PUZZLE

So, if traits are not the *fundamental units of personality* (**Wilt, Condon, Brown-Riddell & Revelle**) what are the basic pieces that make up the personality puzzle? We have suggested that personality components might fulfil that role: behaviours, thoughts and feelings that are associated with a unique causal system. Naturally, and as we have stressed, this definition of personality components is a first step; there is ample opportunity for refining this definition. A good refinement would be to consider more than items from self-report questionnaires (e.g. **Guillaume-Hanes, Morse & Funder; Rothmund, Baumert & Schmitt; Wilt, Condon, Brown-Riddell & Revelle**). For example, **Denissen, Wood and Penke** suggest the inclusion of functionalist components such as the reward value of social situations. With that said, it can be debated whether such functionalist variables act as components in a personality system or, instead, function as external forces that push the personality system towards a certain attractor (e.g. as a moderator that influences the strength between two personality components). Another potential refinement of our original definition is to consider a component as consisting of multiple items. For example, **Costantini and Perugini** suggest that personality components might be better defined at the level of facets (i.e. sub traits one level below the Big Five, for example, assertiveness). We agree that in certain cases, multiple items might be part of the same component, and in that sense, a component might be a facet, and the resulting network might be considered to be a higher level sub-network. In that case, one pragmatically chooses to study relations between sub-networks without assuming them to be fundamental, just as one can study interactions between sub-systems in the brain without phrenological assumptions. However, grouping multiple items would only work when the assumption of local independence is warranted as in the case of multiple thermometers. For example, sleep problems might be assessed by asking the individual, asking his/her spouse and by administering a polysomnography. As such, a measurement temperature model applies, and in that case, a personality component might be a latent variable. This approach would also effectively deal with the problem of incorporating measurement error into the network model (**Asendorpf**).

EAT THE PUDDING!

In our target paper and in this rejoinder, we have articulated a network perspective on personality in which traits result from the mutual interactions between personality components. Additionally, particularly in this rejoinder, we have articulated many reasons why the currently dominant latent trait view is in trouble: traits are probably not latent entities nor do they appear to have explanatory power, rendering the status of the latent trait view as the grand unifying theory of personality problematic. Naturally, criticising existing theories and suggesting new ones necessarily generates critical responses. However, the *concern* that **Schimmack and Gere** expressed over our '. . .suggestion that network analysis provides an alternative account of classic personality constructs. . .' does not make sense in our view, for science cannot progress without regularly questioning the basic assumptions upon which research traditions are founded. That is, in a healthy scientific field, no doors should be closed; indeed, alternative theories should be welcomed, formalised and tested adequately. Regardless of which theory will in the end paint the best picture of how human beings develop unique and yet, in some ways, similar personalities, one should not prematurely throw away the pudding without eating from it first.

ACKNOWLEDGEMENTS

The work of Angélique Cramer and Denny Borsboom was supported by NWO Innovational Research grant number 451-03-068. The work of Sophie van der Sluis was supported by NWO/MaGW VENI-451-08-025 and VIDI-016-065-318.

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