A Logical Deconstruction of Organizational Action: Formalizing Thompson's Organizations in Action into a Multi-agent Logic

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A Case Study in Logical Deconstruction: Formalizing J.D. Thompson's *Organizations in Action* in a Multi-Agent Action Logic

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Abstract

Logic is a popular word in the social sciences, but it is rarely used as a formal tool. In the past, the logical formalisms were cumbersome and difficult to apply to domains of purposeful action. Recent years, however, have seen the advance of new logics specially designed for representing actions. We present such a logic and apply it to a classical organization theory, J.D. Thompson's *Organizations in Action*. The working hypothesis is that formal logic draws attention to some finer points in the logical structure of a theory, points that are easily neglected in the discursive reasoning typical for the social sciences. Examining *Organizations in Action* we find various problems in its logical structure that should, and, as we argue, could be addressed.

> *Jones seeks a unicorn*
> Richard Montague

Keywords: Logic, action logic, formalization, organization theory

1 Introduction

Logic is a popular word in the social sciences, but it is rarely used as a formal tool. The "stats" of modern research have become very advanced, but the logic is usually at the level of weak descriptive statistics.

The absence of formal logic may have been justified by technical reasons in the past. The available formalisms were cumbersome and difficult to apply to domains of purposeful action. Recent years, however, have seen the advance of new, "nonstandard" logics especially designed for representing actions (Harel 1984; Moore 1985; Rao and Georgeff 1991). We are using a multi-agent action logic, ALX.3, to investigate the logical structure of J.D. Thompson's *Organizations in Action* (1967). We chose Thompson's contribution for three reasons: (1) it is one of the few all-time classics of Organization Theory, providing the crucial link between March and Simon's book *Organizations* (1958) and modern contributions to Organization Theory such as Mintzberg's *The Structuring of Organizations* (1979), or Grandori's *Perspectives on Organization Theory* (1987); (2) it has been explicitly developed as an action theory and should provide a good testcase for the use of action logic; (3) it is structured according to explicitly stated propositions, which encourages and facilitates the use of logical instruments.

In formalizing *Organizations in Action* in ALX, we pursue one primary goal: to present a new knowledge representation tool. The working hypothesis is that formal logic draws at-

tention to some finer points in the logical structure of a theory. These finer points are easily neglected in the discursive reasoning typical in the social sciences, but they deserve attention as well. And examining the case of *Organizations in Action* we find various problems in its explanatory structure that should and, as we argue, could be addressed.

The paper is structured as follows. First, we give a brief, informal introduction to the logical machinery. Second, we provide a formal representation of the propositions of Chapter 2 through 4 of OIA (Chapter 1 contains no propositions), plus an explanation of each proposition along the lines of Thompson's reasoning in terms of ALX.3. Finally, we discuss the results in the light of four aspects: (1) the implications of our results for the theory of *Organizations in Action;* (2) the role of formal logic in building or improving theories; (3) the usefulness of action logic; (4) the relation between our work and other recent work on the formalization of organization theory. The paper has two appendices. The first appendix provides a formal description of ALX.3, while the second appendix contains the full set of formulas of the formalization. The appendices should free the main text from technicalities while assuring that informal claims are backed up by formal arguments.

2 ALX, an Action Logic for Agents with Bounded Rationality

We developed ALX as a formal language for social science theories, especially for theories of organizations (Masuch 1992; Huang, Masuch, and Pólos 1992a; Huang, Masuch, and Pólos 1996). It is widely agreed that many social theories are action theories. Yet actions presuppose *attitudes* and engender *change*, and both are notoriously hard to express in the extensional context of standard logics, e.g., First Order Logic (Montague 1974).[1] This explains our attempt to develop a new logic.

Like all modern logics, ALX comes in two parts, *syntax* and *semantics*. The syntax fixes the use of logical and other symbols by defining the elements of the language and legitimate expressions in that language, the *well-formed formulas*. The *semantics* defines the meaning of such formulas. Both syntax and semantics support a notion of logical consequence. The syntactic notion of logical consequence, *derivation*, is used in constructing proofs on the basis of *logical axioms, inference rules*, and *"material" assumptions* that delineate the universe of discourse. The semantic notion of logical consequence is needed to determine the *validity* of the logical axioms, and the *soundness* of the inference rules. A complete axiomatic characterization of a logical system consists of a set of logical axioms plus inference rules to assure that any semantic consequence has a syntactic counterpart, or, informally speaking, that every truth can, in principle, be proven. ALX.3 is complete in this sense.

2.1 The Description Language of ALX.3

The description language of ALX.3 is First-Order Logic. Informally put, we use FOL when attitudes, or change, are not an issue.[2]

FOL can be based on the idea that the world can be represented by a set of objects (the universe of discourse) that either do or do not have certain properties or stand in certain relationships to each other. FOL's language reflects this semantics by having symbols for:

- *Constant names:* names for objects in the domain; we use self-explanatory capitalized strings.
- *Predicate constants:* names for properties of, or relations between, objects; we use capitalized strings of symbols (e.g., $O(i)$ will denote the fact that i is an organization).
- *Variables:* name slots for objects, roughly comparable to pronouns in English; we use lower case letters *a, b, c* for actions, lower case letters *i, j, k* for agents, and *x, y, z* for other arbitrary objects. We may also use indexed letters, e.g., i_1, x_2, etc.
- *Quantifiers:* numerical designators, i.e., "for all" ($\forall$) and "there exists" ($\exists$).
- *Logical connectives:* symbols that allow one to build complex expressions from simple expressions; the five standard connectives are: "$\neg$" (negation, not), "$\vee$" (disjunction, or), "$\wedge$" (conjunction, and), "$\rightarrow$" (conditional, if-then), "$\leftrightarrow$" (biconditional, if and only if (iff)).

A first-order language may also include function symbols, i.e., symbols for *operations*, as well as a symbol for equality. Functions in FOL map objects of the domain to objects of the domain; we distinguish them syntactically by using lower-case strings (e.g., the expression $tc(i)$ denotes the *technical core* of i). In addition, we may use meta-symbols, such as ϕ or ψ, to denote arbitrary well-formed formulas. We will also use notational abbreviations ("syntactic sugar") that are formally not part of the official language when appropriate, i.e., when an effective algorithm can be defined to rewrite the abbreviated formula to a (set of) well-formed formula(s) in the object language.

2.2 Change-Oriented Operators

To express attitudes and change in ALX.3, we have four primitive operators. They are *modal* operators, and their semantics is based on the differentiation between possible worlds.

Herbert A. Simon's original conceptualization of *bounded rationality* serves as a point of departure. Simon wanted to overcome the omniscience claims of the traditional conceptualizations of rational action by assuming (1) an agent, with (2) a set of behavior alternatives, (3) a set of future states of affairs, and (4) a preference order over future states of affairs. The omniscient agent, endowed with "perfect rationality", would know all behavior alternatives and the exact outcome of each alternative; the agent would also have a complete preference ordering for those outcomes. An agent with bounded rationality, in contrast, may not know all alternatives, nor the exact outcome of each alternative; also, the agent may lack a complete preference ordering for those outcomes.

Kripke's *possible world semantics* provides a natural setting for Simon's conceptualization (Simon 1995). We assume a set of possible worlds or *states* (sets of states may also be called situations). An action is a transition from a state to a possibly different state. In provid-

ing this transition, the action makes the new state *accessible*, whence the technical name for behavior alternatives: *accessibility relations*. In ALX.3, accessibility relations are expressed by indexed one-place modal operators, as in dynamic logic. The formula

$$\langle a_i \rangle \phi$$

for instance, expresses the fact that the agent i has an action a at its disposal such that effecting a in the present situation would result in the situation denoted by ϕ.

Preferences—not goals—provide the basic rationale for rational action both in Bounded Rationality and in ALX. Preferences are expressed via an indexed two-place infix operator $\mathbf{P}$; for instance, should agent i prefer an apple to an orange, we can express this by writing

$$Has(i, APPLE)\mathbf{P}_i Has(i, ORANGE)$$

Should agent i have the same preference with respect to agent j, we could write

$$Has(j, APPLE)\mathbf{P}_i Has(j, ORANGE)$$

Should agent i be given to smoking, we could write:

$$Smoking(i)\mathbf{P}_i \neg Smoking(i)$$

Should the agent try to quit smoking, we could write:

$$(\neg Smoking(i)\mathbf{P}_i Smoking(i))\mathbf{P}_i(Smoking(i)\mathbf{P}_i \neg Smoking(i))$$

to express that i would prefer not to prefer smoking. To say that i's case is not hopeless, we could write

$$\langle a_i \rangle(\neg Smoking(i)\mathbf{P}_i Smoking(i))$$

to express that a state is accessible to i where he does not prefer smoking.

Normally, the meaning of a preference statement is context dependent, even if this is not made explicit. An agent may say she prefers an apple to an orange, but she may prefer an orange to an apple later—perhaps because then she already had an apple. To capture this context dependency, we borrow the notion of minimal change from Stalnaker's approach to conditionals (Stalnaker 1968). We introduce a binary function, cw, to the semantics that determines a set of "closest" states relative to a given state, such that the new states fulfill some specified conditions, (CS1-CS5 in the formal semantics), but resemble the old state as much as possible in all other respects.

The syntactic equivalent of the closest world function is the wiggled "causal arrow". It appears in expressions such as

$$\phi \rightsquigarrow \psi$$

where it denotes: in all closest worlds where ϕ holds, ψ also holds. The causal arrow expresses the conditional notion of a causal relation between ϕ and ψ: if ϕ *were* the case, then ψ *would* also be the case. For example, if smoking would always induce a bad conscience in i, we could express this by saying that smoking induces a preference against a preference for smoking:

$$Smoking(i) \leadsto (\neg Smoking(i)\mathbf{P}_i Smoking(i))\mathbf{P}_i(Smoking(i)\mathbf{P}_i \neg Smoking(i))$$

The last primitive operator of ALX is the indexed belief operator. In a world of bounded rationality, an agent's beliefs do not necessarily coincide with reality, and in order to make this distinction, we must be able to distinguish between belief and reality; $\mathbf{B}_i(\phi)$ will represent the fact that agent i believes ϕ. For example, if agent i believes that he could never quit smoking, we could express this by

$$\mathbf{B}_i(\neg \exists a(\langle a_i \rangle \neg (Smoking(i)\mathbf{P}_i \neg Smoking(i))\mathbf{P}_i(Smoking(i)\mathbf{P}_i \neg Smoking(i)))$$

As the logical axioms regarding the belief operator show (Appendix 1), $\mathbf{B}$ represents a sense of "subjective knowledge", not metaphysical attachment, or epistemological uncertainty.

The difference between FOL formulas (formulas which do not have modal operators) and modal formulas (which do) is related to the possible world semantics. FOL formulas are always about the "actual" world, i.e., the domain as it is supposed to be right now. Modal formulas, in contrast, may refer to other possible words. For example, $\langle a_i \rangle \phi$ is true in the actual world if there exists an accessible world (perhaps this one, perhaps another one) where ϕ actually holds.

2.3 Primitives, Definitions, Assumptions

In ALX.3, predicate symbols and modal operators represent basic concepts. Their content may or may not be determined by *definitions*. A definition would fix a concept's content analytically in terms of other concepts. For example, one can define a bachelor in terms of gender and marital status. Not all concepts can be defined, since an attempt to do so would engender an infinite regress, or circularity. Undefined concepts are usually called *primitives*. Primitives are unavoidable on logical grounds, but also when one does not know exactly how to define a concept (e.g., "preferences").

If one has a partial analysis of a concept, but cannot define it completely, *meaning postulates* can help. For example, saying that a bachelor should at least not be married amounts to a meaning postulate. Meaning postulates act as *partial definitions.*

Definitions and meaning postulates determine the analytic content of a concept. Empirical theories would lack substance if they would consist solely of analytical statements; they must also contain contingent assertions, i.e., statements that add to our knowledge beyond establishing analytic conventions. Contingent statements may or may not be true, depending on the true state of the theory's domain;[3] we call them *premises* and refer to them as the premise set Σ.

Contingent statements may be derivable from other statements, in which case they are called *theorems* or *lemmas*. Alternatively, they may have to be asserted as premises of a theory, in which case they are usually called *assumptions* or *material axioms*. For logical reasons, material axioms are a necessity in empirical theories, since no contingent statement could be derived from universally true statements (at least not in a *sound* logic such as ALX.3). Note the difference between *logical* axioms and *material* axioms. Logical axioms contribute to the syntactic characterization of the logical system (e.g., the transitivity of preferences is a logical axiom in ALX). Material axioms, in contrast, characterize the domain of discourse. Note that we are furthermore distinguishing between assumptions pertaining to organization theory, and other assumptions that represent commonsense or background knowledge.

In order to refer to specific formulas, we label them according to their function and their place. (D . . .) indicates a definition, (MP . . .) a meaning postulate, (A . . .) a material axiom, (BK . . .) background knowledge, (L . . .) a lemma, and (T . . .) a theorem. A star qualifies a preliminary or otherwise questionable formula.

2.4 Defined Operators

ALX provides considerable flexibility in defining new modal operators by using the four primitive operators. We concentrate on operators of potential use in the formalization of OIA.

Knowledge.   Knowledge is defined along traditional lines (Cohen and Levesque 1987) as true belief:

$$(\text{D.KN}) \quad \mathbf{K}_i(\phi) \overset{\text{def}}{\Leftrightarrow} \mathbf{B}_i(\phi) \wedge \phi$$

so agent i "really" knows ϕ if the agent believes ϕ and ϕ actually holds. Since the belief operator represents subjective knowledge, the knowledge operator can be understood to represent true subjective knowledge, i.e., "objective" knowledge.

Accessibility.   It is sometimes relevant whether agent i can directly access a particular state via an action, in particular if such a state is a candidate for a goal state. Define direct accessibility as follows:

$$(\text{D.DA}) \quad \mathbf{DA}_i(\phi) \overset{\text{def}}{\Leftrightarrow} \exists a \langle a_i \rangle \phi$$

so a state ϕ is directly accessible if the agent has an action that can bring about ϕ. A state may not be directly accessible, even though it may be accessible via another directly accessible state. Define accessibility:

$$(\text{D.A}) \quad \mathbf{A}_i(\phi) \overset{\text{def}}{\Leftrightarrow} \mathbf{DA}_i(\phi) \vee (\mathbf{DA}_i(\psi) \wedge (\psi \rightsquigarrow \phi))$$

so a state ϕ is accessible if it is either directly accessible or if another state is directly accessible that leads to ϕ.

Good, Bad States.   Define a "good" state ϕ as a state that agent i prefers to its negation, and conversely for a bad state:

(D.GO) $\mathbf{GO}_i(\phi) \overset{\text{def}}{\Leftrightarrow} (\phi\mathbf{P}_i\neg\phi)$ (D.BA) $\mathbf{BA}_i(\phi) \overset{\text{def}}{\Leftrightarrow} (\neg\phi\mathbf{P}_i\phi)$

Elements of the Preference Order.   Define an element of agent i's preference order as follows:

(D.PO) $\mathbf{PO}_i(\phi) \overset{\text{def}}{\Leftrightarrow} (\phi\mathbf{P}_i\rho) \vee (\rho\mathbf{P}_i\phi)$

2.5 Goals

Goals are perhaps the most crucial notion in OIA; most of its propositions hypothesize goals by using the somewhat ceremonial phrase: "Under norms of rationality, organizations *seek to*..." in a strategic way.

Following the basic notions of bounded rationality, goals are derived from preferences in ALX; they are not a primitive notion as in other action logics. But there are many ways to base goals on preferences. At least three issues are important in the present context:

(1) A state may be singled out as a goal for various reasons, it may simply be a good state, or better than others; it may be satisficing, extremal, or optimal.
(2) A potential goal state may be understood in a "qualitative" way (e.g., presence or absence of a state), or it may be considered a matter of degree (e.g., "more or less").
(3) A potential goal state may or may not be believed to be accessible, or its accessibility may be unknown.

Bounded rationality is often identified with the notion that agents do not optimize, at least not in the sense of putting much energy into the search for optimal solutions; instead, they are said to satisfice. However, the reduction of rationality to satisficing is misleading. Satisficing is, indeed, relevant when the existence, or the accessibility, of potential goal states is unknown. If a known alternative meets a given aspiration level, then, as a rule, the agent will not *search* for a better state; conversely, if no known alternative meets the aspiration level, the agent will search for better solutions, at least up to a certain point. However, agents would simply act irrationally if they would not pursue the best known accessible alternative, bypassing other equally accessible, but less preferred, alternatives; if they would not, aspiration levels could only go down. Bounded rationality has been introduced in order to develop a more realistic framework of rational decision making, and maximization and/or optimization are clearly decision modes guiding organizational choice in many cases (when

operations research is applied, for instance). Not surprisingly, OIA does incorporate notions of maximization, and perhaps even optimization, so we need to have corresponding goal concepts to represent these attitudes.

Given the alternatives listed above, agents "under norms of rationality" can be expected to respect some minimal requirements:

- Goal states should not believed to be inaccessible.
- A potential goal state should not block better, equally accessible states; so if ϕ and ψ are both believed to be equally accessible, and ϕ is preferred to ψ, and, furthermore, ψ would make ϕ inaccessible, then ψ does not qualify as a goal state.

To reflect these minimal requirements in the goal definitions to come, we need a caveat, and propose the following definition ($\mathbf{C}$ is a mnemonic for "caveat" here):

$$(\text{D.C}) \quad \mathbf{C}_i(\phi)(\overset{\text{def}}{\Leftrightarrow} \neg\mathbf{B}_i(\neg\mathbf{A}_i(\phi) \wedge \exists\psi(\mathbf{A}_i(\psi) \wedge (\psi\mathbf{P}_i\phi) \wedge (\phi \rightsquigarrow \neg\mathbf{A}_i(\psi))))$$

(read: ϕ satisfies the minimal requirement for goals "$\mathbf{C}_i(\phi)$", if ϕ is not believed to be inaccessible "$\neg\mathbf{B}_i(\neg\mathbf{A}_i(\phi))$", and it is not believed that (1) there exists a situation ψ that is accessible "$\mathbf{A}_i(\psi)$", (2) is preferred to ϕ, "$\psi\mathbf{P}_i\phi$", (3) and that would become inaccessible in situation "ϕ ($\phi \rightsquigarrow \neg\mathbf{A}_i(\psi))$[4]".

We are now ready for the first goal definition. Agents might opt for a state simply because it is better than its negation, particularly if only few alternatives are considered—provided there are no obvious better choices: We can define the "good" goal by using the "good" operator $\mathbf{GO}_i$ and the $\mathbf{C}_i$-condition just defined:

$$(\text{D.G.G}) \quad \mathbf{G}_i^g(\phi) \overset{\text{def}}{\Leftrightarrow} \mathbf{GO}_i(\phi) \wedge \mathbf{C}_i(\phi)$$

The second definition involves a satisficing goal. Because of the specific nature of satisficing behavior (which depends, among other things, on the agent's history), we have no definition of a satisficing state at this point. The only thing we can posit right now is that a state is satisficing for agent i only if it is an element of i's preference order:

$$(\text{MP.S.1}) \quad \mathbf{S}_i(\phi) \Rightarrow \mathbf{PO}_i(\phi)$$

Define a satisficing goal in terms of a satisficing state that obeys the goal caveat:

$$(\text{D.G.S}) \quad \mathbf{G}_i^s(\phi) \overset{\text{def}}{\Leftrightarrow} \mathbf{S}_i(\phi) \wedge \mathbf{C}_i(\phi)$$

Thus a goal is satisficing if the goal-state is satisficing and does not block better states known to be accessible.

In the case of an outstanding, or "best" choice, the definition should assure that there is no better accessible state:

$$(\text{D.G.BC}) \quad \mathbf{G}_i^{bc}(\phi) \overset{\text{def}}{\Leftrightarrow} (\phi\mathbf{P}_i\rho) \wedge \forall\psi(\psi\mathbf{P}_i\phi \rightarrow \mathbf{B}_i(\neg\mathbf{A}_i(\psi)))$$

(read: ϕ is a best-choice goal, if ϕ is a preferred state "$\phi\mathbf{P}_i\rho$", and all states that are preferred to ϕ are believed to be inaccessible "$\forall\psi(\psi\mathbf{P}_i\phi \rightarrow \mathbf{B}_i(\neg\mathbf{A}_i(\psi)))$")

Thus a best choice involves a preferred state to which no other state is preferred that is believed to be accessible. Ironically, best choices need be neither good nor satisficing; in a tight spot, the agent's best alternative might simply be the best among undesirable alternatives.

Sometimes, extreme values of specific dimensions assume a special place in a preference ordering; in OIA, for example, organizations seek to minimize uncertainty. The corresponding goals are not necessarily maximal elements in the preference ordering as such, but they are extreme in the ordering as far as a particular dimension (e.g., uncertainty) is concerned. We introduce some syntactic sugar to represent these elements. Let Φ stand for a particular dimension, and let x_1, x_2 be arbitrary "values" of dimension Φ. Let furthermore $\Phi(i, x)$ express the fact that x is a value of dimension Φ with respect to i. Then we can define

$$(\text{D.G.CBC}) \quad \mathbf{G}_i^{bc(\Phi)}(\Phi(i, x)) \overset{\text{def}}{\Leftrightarrow} (\Phi(i, x)\mathbf{P}_i\rho) \wedge \forall y(\Phi(i, y)\mathbf{P}_i\Phi(i, x)$$
$$\rightarrow \neg\mathbf{B}_i(\mathbf{A}_i(\Phi(i, y))))$$

(read: x is agent i's best choice on dimension "Φ ($\mathbf{G}_i^{bc(\Phi)}(\Phi(i, x))$)", if and only if i has a preference for this value "$\Phi(i, x)\mathbf{P}_i\rho$", and all more preferred values of this dimension are believed to be inaccessible "$\forall y(\Phi(i, y)\mathbf{P}_i\Phi(i, x) \rightarrow \neg\mathbf{B}_i(\mathbf{A}_i(\Phi(i, y))))$")

so that a best choice with respect to dimension Φ is the most preferred value of dimension Φ not believed to be inaccessible.

Table 1 gives an overview of all modal operators.

Table 1. Overview of Operators.

Operator	Meaning	Definition	Example	
$\langle a_i \rangle$	action	primitive	$\langle a_i \rangle\phi$	ϕ is accessible for i via action a
$\mathbf{P}_i$	preference	primitive	$\phi\mathbf{P}_i\psi$	i i prefers ϕ to ψ
$\leadsto$	causal conditional	primitive	$\phi \leadsto \psi$	in all closest worlds where ϕ holds, ψ also holds
$\mathbf{B}_i$	belief	primitive	$\mathbf{B}_i(\phi)$	i believes ϕ
$\mathbf{K}_i$	knowledge	(D.KN)	$\mathbf{K}_i(\phi)$	i knows ϕ
$\mathbf{DA}_i$	direct accessibility	(D.DA)	$\mathbf{DA}_i(\phi)$	ϕ is directly accessible for i
$\mathbf{A}_i$	accessibility	(D.A)	$\mathbf{A}_i(\phi)$	ϕ is accessible for i
$\mathbf{GO}_i$	"good"	(D.GO)	$\mathbf{GO}_i(\phi)$	ϕ is "good" in i's view
$\mathbf{BA}_i$	"bad"	(D.BA)	$\mathbf{BA}_i(\phi)$	ϕ is "bad" in i's view
$\mathbf{PO}_i$	preference order	(D.PO)	$\mathbf{PO}_i(\phi)$	ϕ occurs in i's preference order
$\mathbf{C}_i$	goal caveat	(D.C)	$\mathbf{C}_i(\phi)$	ϕ does not block better goals of i
$\mathbf{S}_i$	satisficing state	(MP.S.1)	$\mathbf{S}_i(\phi)$	ϕ is a satisficing state for i
$\mathbf{G}_i^g$	"good" goal	(D.G.G)	$\mathbf{G}_i^g(\phi)$	ϕ is a "good" goal of i
$\mathbf{G}_i^s$	satisficing goal	(D.G.S)	$\mathbf{G}_i^s(\phi)$	ϕ is a satisficing goal of i
$\mathbf{G}_i^{bc}$	optimal goal	(D.G.BC)	$\mathbf{G}_i^{bc}(\phi)$	ϕ is a optimal goal ("best choice" of i)
$\mathbf{G}_i^{bc(\Phi)}$	restricted optimal goal	(D.G.CBC)	$\mathbf{G}_i^{bc(\Phi)}(\phi)$	ϕ is i's best choice w.r.t dimension Φ

3 Formalizing Organizations in Action

Having presented an account of the formal machinery, we now proceed to show it in action: formalizing an important organization theory. The theory of choice is J.D. Thompson's *Organization in Action*, which is still inspiring much of today's organization theory. The best introduction to *Organizations in Action* is perhaps in Thompson's own words:

> "Organizations act, but what determines how and when they will act? (. . .) We will argue that organizations do some of the basic things they do because they must—or else! Because they are expected to produce results, their actions are expected to be reasonable or rational. The concepts of rationality brought to bear on organizations establish limits within which organizational action must take place. We need to explore the meanings of these concepts and how they impinge on organizations. Uncertainties pose major challenges to rationality, and we will argue that technologies and environments are basic sources of uncertainty for organizations. How these facts of organizational life lead organizations to design and structure themselves needs to be explored.
>
> "If these things ring true, then those organizations with similar technological and environmental problems should exhibit similar behavior; patterns should appear. But if our thesis is fruitful, we should also find that patterned variations in problems posed by technology and environments result in systematic differences in organizational action . . . "(OIA: 1-2)

In Part I of his book, Thompson examines the genesis of such patterns from the point of view of one single organizational agent ("the organizations under norms of rationality"); Part II investigates the role of individuals in organizations, and how individual and organizational goals may interact. In modern parlance, Part I is about Organization Theory, Part II is about Organizational Behavior.

The "central theme of the book is that organizations abhor uncertainty" (OIA: 79). Being open systems, however, organizations cannot avoid uncertainty, so they have to manage uncertainty somehow, and one way of doing this is by distributing it unevenly across organizational levels. Chapter 1 distinguishes three such levels: (1) a technological level, (2) an institutional level, and (3) a managerial level; the managerial level mediates between the technological level and the institutional level. As a meta-chapter about organizational theory, Chapter 1 does not contain any explicit propositions.

3.1 Rationality and Technology

Chapter 2 is titled "Rationality in Organization", but its focus is primarily on the rationality of the technological level, or "technological core". In Thompson's analysis, the technological level requires special protection. If uncertainty impinges on the outcome of a decision, then the factors of the decision making process are not completely under control; but technical rationality (and hence the rationality of the technical core) is at stake for as long as the outcome (technical rationality's criterion) remains uncertain. "Sealing off" is Thompson's phrase for protecting the technical core against uncertainty. The first proposition summarizes this analysis; the remaining four propositions specify further the meaning of "sealing off". Here is the first proposition:

Proposition 2.1. *Under norms of rationality, organizations seek to seal off their core technologies from environmental influences.*

For the formal representation of this proposition, we let the expression $O(i)$ stand for the fact that i is an organization, and $R(i)$ for the fact that i is rational. Define the abbreviation $RO(i)$ (*rational organization*) as follows:

(D.RO) $\forall i(RO(i) \leftrightarrow (R(i) \wedge O(i)))$

(read: for all i, i is a rational organization, if and only if i is an organization and i is rational)

Let the expression $So(i)$ denote the fact that i is sealed off, and let furthermore the expression $tc(i)$ (a function) denote i's technical core, then we can represent a preliminary version of Proposition (2.1) as follows:

(T.2.1*) $\forall i(RO(i) \rightarrow \mathbf{G}_i(So(tc(i))))$

(read: for all i, if i is a rational organization, then i's goal is to seal-off its technical core)

We have yet to determine the type of goal in (2.1). The context seems to suggest "minimizing uncertainty", and hence a "best choice" regarding the uncertainty dimension along the line of definition (D.G.CBC). If organizations abhor uncertainty, and if uncertainty has its worst effects in the technical core, rational organizations may want to minimize uncertainty at the technological level. However, the literal text of the proposition (2.1) itself uses a qualitative conceptualizing of "sealing-off". Sealing off protects the technical core against uncertainty, and is hence preferred to "not-sealing off"; so we seem to have a "good" goal in the sense of (D.G.G).

(T.2.1) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(So(tc(i))))$

Arguing for (T.2.1) means writing down in formal terms why "sealing off" is a good choice of rational organizations. To say that rational organizations have a preference against an uncertain technical core, we use the **BA** ("bad") operator, which denotes a negative element in agent i's preference order. Furthermore, we use the expression $U(x)$ to say that x is subjected to uncertainty. Then we can write:

(A.2.1.1) $\forall i(RO(i) \rightarrow \mathbf{BA}_i(U(tc(i))))$

(read: for all i, if i is a rational organization, then i has a preference against uncertainty affecting its technical core)

From (A.2.1.1) and the definitions (D.GO) and (D.BA) it follows immediately that the negation of "$U(tc(i))$" is "good":

(L.2.1.1) $\forall i(RO(i) \rightarrow \mathbf{GO}_i(\neg U(tc(i))))$

We can furthermore assume that an unprotected technical core is exposed to uncertainty.

(A.2.1.2) $\forall i(RO(i) \rightarrow (\neg So(tc(i)) \rightsquigarrow (U(tc(i)))))$

(read: for all i, if i is a rational organization, then its technical core not being sealed off causes its technical core being exposed to uncertainty)

Conversely, we assume that a sealed-off technical core is not exposed to uncertainty. This assumption is perhaps too strong, but we accept it as a simplification due to the use of a dichotomous dimension:

(A.2.1.3) $\forall i(RO(i) \rightarrow (So(tc(i)) \rightsquigarrow (\neg U(tc(i)))))$

We can combine both assumptions since they have identical antecedents:

(A.2.1.4) $\forall i(RO(i) \rightarrow ((\neg So(tc(i)) \rightsquigarrow U(tc(i))) \wedge (So(tc(i)) \rightsquigarrow \neg U(tc(i)))))$

To satisfy the definition of $\mathbf{G}_i^g$, we must furthermore assume that sealing off does not "block" other goals in the sense of the $\mathbf{C}$-caveat (cf. definition (D.C)) and that it is not believed inaccessible. OIA does not suggest otherwise at this point, so we assume:

(A.2.1.5) $\forall i(RO(i) \rightarrow \mathbf{C}_i(So(tc(i))))$

(read: for all i, if i is a rational organization, then sealing-off its technical core does not block the pursuit of better goals)

It may seem that these assumptions should suffice to derive (T.2.1). Here is an outline of a proof:

(1)	$\forall i(RO(i) \rightarrow \mathbf{BA}_i(U(tc(i))))$	(A.2.1.1)
(2)	$\forall i(RO(i) \rightarrow \neg U(tc(i))\mathbf{P}_i U(tc(i)))$	(from (2), (D.BA))
(3)	$\forall i(RO(i) \rightarrow \neg U(tc(i))\mathbf{P}_i \neg \neg U(tc(i)))$	(from (3), (SUBP))
(4)	$\forall i(RO(i) \rightarrow \mathbf{GO}_i(\neg U(tc(i))))$	(from (4), (D.GO))
(5)	$\forall i(RO(i) \rightarrow ((\neg So(tc(i)) \rightsquigarrow U(tc(i))) \wedge (So(tc(i)) \rightsquigarrow \neg U(tc(i)))))$	(A.2.1.4)
(6)	$\forall i(RO(i) \rightarrow \mathbf{C}_i(So(tc(i))))$	(A.2.1.5)
$\vdots$		
(?)	$\forall i(RO(i) \rightarrow \mathbf{G}_i^g(So(tc(i))))$	(from ?)

As it turns out, we have a problem with the last step. We cannot satisfy the definition of $\mathbf{G}_i^g$ with respect to $So(tc(i))$. Sealing-off may not block better states, but is it itself a good state?

There are basically two answers. Either we introduce the construction of a goal that would be pursued solely for its "instrumental" properties and would not require any preference commitment; sealing-off may play the role of such an instrumental goal. Alternatively, we could try to establish that the state of sealing off is preferred because it leads to a preferred state. We opt for the second solution, because it does not force us to complicate the framework by introducing a new class of goal concepts. Furthermore, it seems that the distinction between final goals and instrumental goals is difficult to maintain since there are very few goals in the world of organizations (perhaps none) that are not pursued in search of other goals.

Adopting the second option, we need an additional assumption that ascertains that rational agents maintain their attitude with respect to a cause, if they have adopted this attitude with respect to the effect. Obviously, this assumption requires specific caveats, but we postpone the discussion of these caveats (as drug addicts may easily recognize):

$$(\text{BK.P.1*}) \quad ((\phi \mathbf{P}_i \phi') \wedge (\psi \rightsquigarrow \phi) \wedge (\psi \rightsquigarrow' \phi')) \Rrightarrow \psi \mathbf{P}_i \psi'$$

(read: if ϕ is preferred to ϕ' and if ψ leads to ϕ, whereas ψ' leads to ϕ', then ψ is preferred to ψ'.)

With (BK.P.1*) in place, we can finally derive (T.2.1):

(1)	$\forall i(RO(i) \rightarrow \mathbf{BA}_i(U(tc(i))))$	A.2.1.1
(2)	$\forall i(RO(i) \rightarrow \neg U(tc(i))\mathbf{P}_i U(tc(i)))$	from (2), (D.BA)
(3)	$\forall i(RO(i) \rightarrow \neg U(tc(i))\mathbf{P}_i \neg \neg U(tc(i)))$	from (3), (SUBP)
(4)	$\forall i(RO(i) \rightarrow \mathbf{GO}_i(\neg U(tc(i))))$	from (4), (D.GO)
(5)	$\forall i(RO(i) \rightarrow ((\neg So(tc(i)) \rightsquigarrow U(tc(i)))) \wedge (So(tc(i)) \rightsquigarrow \neg U(tc(i))))$	A.2.1.4
(6)	$\forall i(RO(i) \rightarrow \mathbf{C}_i(So(tc(i))))$	A.2.1.5
(7)	$\forall i(RO(i) \rightarrow So(tc(i))\mathbf{P}_i \neg So(tc(i)))$	from (2), (5), (BK.P.1*)
(8)	$\forall i(RO(i) \rightarrow \mathbf{G}_i^g(So(tc(i))))$	from (6), (7), (D.G.G) QED

The remaining propositions of the chapter can be read as partial specifications of the meaning of "sealing off":

Proposition 2.2. *Under norms of rationality, organizations seek to buffer environmental influences by surrounding their technical cores with input and output components.*

Proposition 2.3. *Under norms of rationality, organizations seek to smooth out input and output transactions.*

Proposition 2.4. *Under norms of rationality, organizations seek to anticipate and adapt to environmental changes which cannot be buffered or levelled.*

Proposition 2.5. *When buffering, levelling, and forecasting do not protect their technical cores from environmental fluctuations, organizations under norms of rationality resort to rationing.*

One could assume that buffering, smoothing, and anticipating with respect to the technical core are "good" in the sense of (D.G.G) (rationing is, of course, a different case and requires a different treatment). OIA suggests that buffering et al. contribute to a reduction of uncertainty, and hence are preferred to their negation (the criterion of being "good" in our terminology). However, OIA leads us to believe that none of these activities alone would suffice to seal off the technical core sufficiently under normal circumstances; so we cannot use (BK.P.1*) since it would not be true that "*Buffered(i) $\rightsquigarrow$ Sealed-off(i)*".

We have two options at this point. We could introduce an additional preference postulate that would connect the preference for a conjunction of states with a preference for each of its conjuncts (the idea being that rational organizations prefer buffering because it is a conjunct

in the *definiens* of sealing-off). Alternatively, we could try to grasp the gradual effect that each activity is supposed to have on the reduction of the uncertainty of the technical core. We opt for the second solution, since its explanatory power appears to be stronger.

To begin, let $Bu(tc(i))$ stand for a technical core which is buffered, $Sm(tc(i))$ for a technical core whose input and output is smoothed, and $AA(tc(i))$ for a technical core whose environmental fluctuations are anticipated and that is adapted accordingly, then we can represent (2.2) through (2.4) as follows:

(T.2.2) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(Bu(tc(i))))$

(T.2.3) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(Sm(tc(i))))$

(T.2.4) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(AA(tc(i))))$

The "good" property of buffered states is proposed as a lemma:

(L.2.2.1) $\forall i(RO(i) \rightarrow \mathbf{GO}_i(Bu(tc(i))))$

The lemmas for smoothing and anticipation are written in the same way by replacing the *Bu* predicate accordingly; this yields the corresponding lemmas (L.2.3.1) and (L.2.4.1).

We must now explain why the lemmas (L.2.2.1) through (L.2.4.1) hold, and furthermore establish that buffering, smoothing et al. do not block other, more preferred states.

Now, the lemmas should hold since OIA suggests that rational organizations (1) prefer less to more uncertainty, (2) that buffering et al. contribute to a reduction of uncertainty, and hence (3) that buffering et al. are preferred to their respective negation.

Let $UV(tc(i), x)$ denote the fact that x is the uncertainty value of i's technical core, then (1) can be represented as follows:

(A.2.2.1) $\forall i, u_1, u_2((RO(i) \wedge (u_1 < u_2)) \rightarrow UV(tc(i), u_1)\mathbf{P}_i UV(tc(i), u_2))$

(read: for all i, u_1, and u_2, if i is a rational organization and u_1 is smaller than u_2, then i will prefer u_1 to u_2 as the value of the uncertainty of its technical core)

To express that buffering contributes to a reduction of uncertainty, we have to state that a buffered technical core features less uncertainty than an unbuffered one :

(A.2.2.2) $\forall i, \exists u_1, u_2(RO(i) \rightarrow ((u_1 < u_2) \wedge (Bu(tc(i)) \rightsquigarrow UV(tc(i), u_1))$
$\wedge (\neg Bu(tc(i)) \rightsquigarrow UV(tc(i), u_2))))$

(read: for all i, if i is a rational organization, then there exist values u_1 and u_2 such that u_1 is smaller than u_2, and buffering i's technical core leads to the uncertainty-value u_1, whereas not buffering i's technical core leads to the uncertainty-value u_2)

Smoothing and anticipation/adaptation can be represented in similar fashion; this yields (A.2.3.2) and (A.2.4.2).

Lemma (L.2.2.1) is now an easy consequence of (A.2.2.1), (A.2.2.2), and (BK.P.1*), provided that we assert the technical background assumption that organizations always feature a unique (perhaps zero) value of uncertainty:

(BK.U.1) $\forall i, u_1, u_2((RO(i) \wedge UV(i, u_1)) \wedge UV(i, u_2)) \rightarrow (u_1 = u_2))$

(read: for all i, if i is a rational organization, and u_1 and u_2 are two values representing the uncertainty to which i is exposed, then the two values are identical)

(BK.U.2) $\forall i, \exists u(RO(i) \rightarrow UV(i, u))$

(read: for all i, if i is a rational organization, then there exists a value u that represents the uncertainty to which i is exposed)

The corresponding lemmas (L.2.3.1) and (L.2.4.1) are derived in parallel.

To derive (T.2.2) et al., we must also assure that (D.G.G) is satisfied, and this requires the caveat regarding better accessible goals. As it turns out, OIA is not sanctioning this caveat unconditionally. In extreme situations, OIA stipulates, buffering may become too "costly" and may conflict with less buffered, but also less costly states, so that organizations may refrain from extreme forms of buffering. In such cases, the caveat $C_i(Bu(tc(i)))$ would not hold, because the definiens of C_i might not be fulfilled; organizations may prefer a less costly, but also less buffered state that is not believed to be inaccessible.

Unfortunately, it would complicate things quite a lot to deal with the problem at this point, so we flag the corresponding assumptions for later treatment:

(A.2.2.3*) $\forall i(RO(i) \rightarrow C_i(Bu(tc(i))))$

As before, smoothing and anticipation/adaptation are treated in parallel.

Given (A.2.2.3*) et al., (T.2.2) et al. now follow from (L.2.2.1) et al., and (A.2.2.3*) et al. via instantiations of (D.G.G).

We could assume that buffering, smoothing, and anticipation/adaptation are "good". However, we cannot assume that rationing is "good". Rationing is clearly seen as a measure of last resort in OIA, used solely by rational organizations when all other sealing-off activities are not effective enough. This, ironically, turns rationing into a best choice. On the condition that buffering, smoothing, and anticipation/adaptation together are not satisficing, rationing is the only remaining acceptable choice, and hence a maximal element in the preference order not believed to be inaccessible.

The corresponding formal representation of proposition (2.5) is (letting $Rat(x)$ standing for x being protected by rationing):

(T.2.5) $\forall i(RO(i) \wedge \neg(S_i(Bu(tc(i)) \wedge Sm(tc(i)) \wedge AA(tc(i)))) \rightarrow G_i^{bc}(Rat(tc(i))))$

(read: for all i, if i is a rational organization, and the situation where its technical core is buffered, smoothed, and its environment is anticipated is not satisficing, then rationing becomes a goal)

(T.2.5) becomes derivable on the assumption:

(A.2.5.1*) $(RO(i) \wedge \neg(S_i(Bu(tc(i)) \wedge Sm(tc(i)) \wedge AA(tc(i)))))$

for a particular organization i. Whether, or more precisely, when (A.2.5.1*) holds remains undetermined, however. OIA does not elaborate on its conditions, hence the star.

This concludes the formalization of Chapter 2 of OIA. We have kept the argument simple, since we have still a long way to go; the discussion of some problems has been postponed. There is a problem with the dichotomous representation of uncertainty: does it make sense to assume that a technical core could be completely sealed off? Furthermore, we had to flag the goal-caveat (A.2.2.3*) regarding better accessible goals with respect to buffering (and possibly other sealing-off activities as well). The quest for certainty may become excessively costly, and hence unsustainable, so there is a potential goal conflict here.

3.2 Dependence and Power

Titled *Domains of Organized Action*, Chapter 3 is about the management of dependence; all its theorems address the questions how organizations can reduce their dependency on specific elements of the environment.

The two crucial concepts of the chapter are *dependence* and *power*. An organization is "dependent on some element of its task environment (1) in proportion to the organization's need for resources or performances which that element can provide and (2) in inverse proportion to the ability of other elements to provide the same resource or performance" (OIA: 30). Power is defined as the "obverse" of dependence, "thus an organization has power, relative to an element of its task environment, to the extent that the organization has capacity to satisfy needs of that element and to the extent that the organization monopolizes that capacity" (OIA: 30-31). As a consequence, power and dependence are interdefinable: let $Dep(i, j)$ stand for the fact that i depends on j, and $Pow(i, j)$ for the fact that i has power over j):

(D.POW) $\forall i, j(Pow(i, j) \leftrightarrow Dep(j, i))$

(read: for all i, j, i has power over j, if and only if j depends on i)

If the set of alternative agents k is large enough, "perfect competition" with respect to resource x is approximated; if the set is small, competition is "imperfect".

If i is dependent on j, j may exploit its power over i, which "poses contingencies" for i, and the threat of contingencies entails uncertainty. Hence the first proposition:

Proposition 3.1. *Under norms of rationality, organizations seek to minimize the power of task-environment elements over them by maintaining alternatives.*

As opposed to the case of proposition (2.1), the wording of (3.1) appears to force the use of a best-choice goal $\mathbf{G}_i^{bc}$. If rational organizations are striving to minimize dependence, then a state of minimal dependence is a conditional best choice. Now, if they prefer minimal

dependence, we can assume that they prefer less to more dependence across the whole range of dependence values. Let $DepV(i, v)$ represent i's dependence value then we can posit, analogous to (A.2.2.1):

(A.3.1.1) $\forall i, v_1, v_2(RO(i) \wedge (v_1 < v_2) \rightarrow (DepV(i, v_1)\mathbf{P}_i DepV(i, v_2)))$

Given this preference, the best state not deemed inaccessible provides a reasonable candidate for a goal definition. Call such a state $DepV(i, v, MIN))$ and define:

(D.MinDep) $\forall i, v(RO(i) \rightarrow (DepV(i, v, MIN) \leftrightarrow \mathbf{G}_i^{bc(DepV)}(DepV(i, v))))$

(read: for all i, v, define v as the minimal dependency value of i if v is i's best choice with respect to dependency)

So, having this notion of a reasonable state of minimal dependence, we can express proposition (3.1) as follows:

(T.3.1*) $\forall i, \exists v(RO(i) \rightarrow \mathbf{G}_i^{bc(DepV)}(DepV(i, v)))$

(read: for all i, there exists a v, such that if i is a rational organization, then v is i's best choice as the value of its overall dependency.)

Unfortunately, (T.3.1*) does not fully express proposition (3.1), since the proposition requires explicitly that the activity of maintaining alternatives is employed to minimize dependence. Why? The answer seems to be that rational organizations cannot achieve a state of minimal dependence *directly*, or, more precisely, that they *know* that minimal dependence is not directly accessible. There is no direct action "minimize dependence", as it were. We have the $\mathbf{DA}_i$ operator and the $\mathbf{K}_i$ operators (compare definitions (D.DA) and (D.KN)) to express this assumption:

(A.3.1.2) $\forall i, v(RO(i) \rightarrow \mathbf{K}_i \neg \mathbf{DA}_i(DepV(i, v, MIN)))$

We use the knowledge operator, and not the belief operator, because we would get a different theory if organizations could be wrong about "$\neg \mathbf{DA}_i(DepV(i, v, MIN))$."

The theory claims, on the other hand, that there is an *indirect* way of minimizing dependence by bringing about a state in which the organization maintains alternatives. So, we seem entitled to assume (with $MA(i)$ standing for the fact that i maintains alternatives):

(A.3.1.3) $\forall i, \exists v(RO(i) \rightarrow (MA(i) \rightsquigarrow DepV(i, v, MIN)))$

and furthermore that there is a direct action believed to bring about this state:

(A.3.1.4) $\forall i(RO(i) \rightarrow \mathbf{B}_i(\mathbf{DA}_i(MA(i))))$

Taking into account that "minimal dependence" is not directly accessible, we can now represent (3.1) by:

(T.3.1) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(MA(i)))$

for which (T.3.1.*) should provide an explanation. Note that we can stick to a "good" goal here, since the wording of the text is in qualitative terms; no maximizing is required. Since (T.3.1.*) requires itself an explanation, however, we present it as a lemma ((T.3.1*) renamed):

(L.3.1.1) $\forall i, \exists v(RO(i) \rightarrow \mathbf{G}_i^{bc(DepV)}(DepV(i, v)))$

The explanatory link between (L.3.1) and (T.3.1) seems simple: if a goal-state is only accessible via the causal consequences of another state, then this other state may become an (intermediate) goal state. (BK.P.1*) states this principle at the level of preferences; (BK.P.2) state the same principle at the level of goals.

(BK.P.2) $\mathbf{G}_i(\phi) \wedge (\psi \rightsquigarrow \phi) \wedge \neg\mathbf{DA}_i(\phi) \wedge \mathbf{C}_i(\psi) \Rrightarrow \mathbf{G}_i(\psi)$

(read: If ϕ is agent i's goal, and ϕ is caused by ψ, and ϕ is not directly accessible, and, furthermore, ψ would not block better goals, then ψ becomes i's goal.)

Note that we need no special caveat in the case of (BK.P.2), because we already have the goal-caveat, hence there is no need to star this principle. With (BK.P.2) in place, we can derive (T.3.1) from (L.3.1.1), provided that "maintaining alternatives" does not block better goals.[5] OIA would not suggest otherwise, so we assert:

(A.3.1.5) $\forall i(RO(i) \rightarrow \mathbf{C}_i(MA(i)))$

A formal proof of (T.3.1) now runs as follows

(1)	$\forall i, v_1, v_2(RO(i) \wedge (v_1 < v_2) \rightarrow (DepV(i, v_1)\mathbf{P}_i DepV(i, v_2)))$	(A.3.1.1)
(2)	$\forall i, \exists v(RO(i) \rightarrow DepV(i, v, MIN))$	(from (1), (BP.P.2.2))
(3)	$\forall i, \exists v(RO(i) \rightarrow \mathbf{G}_i^{bc(DepV)}(DepV(i, v)))$	(from (2), (D.MinDep))
(4)	$\forall i, \exists v(RO(i) \rightarrow \mathbf{G}_i^{bc(DepV)}(DepV(i, v)) \wedge (MA(i) \rightsquigarrow DepV(i, v, MIN))$	(from (3), (A.3.1.3))
(5)	$\forall i, \exists v(RO(i) \rightarrow \mathbf{G}_i^{bc(DepV)}(DepV(i, v)) \wedge (MA(i) \rightsquigarrow DepV(i, v, MIN)))$ $\wedge \neg\mathbf{DA}_i(DepV(i, v, MIN)))$	(from (4), (A.3.1.2))
(6)	$\forall i(RO(i) \rightarrow \mathbf{C}_i(MA(i)))$	(A.3.1.5)
(7)	$\forall i(RO(i) \rightarrow \mathbf{G}_i^g(MA(i)))$	(from (5), (6), (BP.P.2.1) QED)

The next proposition, (3.2), is something of an outsider; it makes little use of OIA's conceptual machinery, except for the fact that its explanation relates "prestige" to dependence:

Propostion 3.2. *Organizations subject to rationality norms and competing for support seek prestige.*

The proposition is explained by the assumption that organizations can gain some independence via prestige since other agents prefer to deal with prestigious organizations. As the reasoning supporting (3.2) goes, prestige is good, and hence pursued, which suggests the use of (D.G.G) in the representation of the proposition's goal concept. Let $Pr(i)$ stand for the fact that i enjoys prestige, then we can represent (3.2) as follows:

(T.3.2) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(Pr(i)))$

The theory asserts that prestige is good since it is related to less dependence (the formula is analogous to A.2.2.2):

(A.3.2.1) $\forall i, \exists v_1, v_2(RO(i) \rightarrow ((v_1 < v_2) \wedge (Pr(i) \rightsquigarrow DepV(i, v_1))$
$\wedge (\neg Pr(i) \rightsquigarrow DepV(i, v_2))))$

Furthermore, the theory makes no mention of possibly conflicting accessible goals:

(A.3.2.2) $\forall i(RO(i) \rightarrow \mathbf{C}_i(Pr(i)))$

With the last two assumptions, (D.G.G) is satisfied via (BK.P.1*), and (T.3.2) is derivable.

Proposition (3.2) poses no particular formal difficulties. But there are problems in its semantics: why should other agents bother about i's prestige if they know—being rational agents themselves—that prestige's purpose is to weaken their position vis á vis organization i? Conversely, if other agents are not rational enough to know about prestige's effects, why should i be an exception and be rational enough? Yet if i is an exception in being rational, then most organization would not be rational enough and the rationale of the whole theory ("organizations have to be rational or else ... ") would be lost.

Be this as it may, we carry on and move to the next proposition.

As opposed to the first two propositions, Proposition (3.3) is conditioned on the case of imperfect competition:

Propostion 3.3. *When support capacity is concentrated in one or a few elements of the task environment, organizations under norms of rationality seek power relative to those on whom they are dependent.*

If support capacity is concentrated, then alternatives are not maintained automatically, as is assured in the case of perfect competition. If the number of potential alternatives is small, organizations have no viable exit-threat, and must compensate for dependency by creating counter-dependency, as it were.

The literal text of (3.3) does not stipulate a maximizing goal. A possible explanation could be the gap between overall dependence and the specific dependence on an individual element of i's task environment;[6] This gap might invite a disaggregation fallacy, that is, an unjustified jump from the overall minimization to minimization in each specific case. Anyhow, a maximizing goal would obviously misrepresent the wording of (3.3), so we use (D.G.G) in (3.3)'s formal representation. Let $Impcomp(i, j)$ denote the fact that i is with respect to j in a position of imperfect competition (so there are few alternatives for j):

(T.3.3) $\forall i, j((RO(i) \wedge Dep(i, j) \wedge Impcomp(i, j)) \rightarrow \mathbf{G}_i^g(Dep(j, i)))$

To prove (T.3.3), we must explicate the connection between dependency reversal and the resulting reduction of dependency:

(A.3.3.1) $\forall i, j, \exists v_1, v_2(RO(i) \wedge Dep(i, j) \rightarrow ((v_1 < v_2) \wedge (Dep(j, i) \leadsto DepV(i, v_1))$
$\wedge (\neg Dep(j, i) \leadsto DepV(i, v_2))))$

(read: for all i, j, if i is a rational organization, and i is dependent on j, then there exists values v_1, v_2, such that v_1 is smaller than v_2 and j's dependence on i will lead to dependence v_1 for i, whereas j not being dependent on i will lead to dependence v_2 for i)

Note that (A.3.3.1) need not be conditioned on imperfect competition since the fact that dependency reversal reduces dependency should be true (or false) regardless of the type of competition; in fact, (A.3.3.1) is a generalization of (A.3.2.1), where the dependency relation is implicit in i's prestige.

Finally, we have to assure that dependency reversal does not block other goals:

(A.3.3.2) $\forall i((RO(i) \wedge Dep(i, j)) \rightarrow C_i(Dep(j, i)))$

Again, there is no reason to restrict (A.3.3.2) to imperfect competition.

The formal proof of (T.3.3) is now as follows:

(1)	$\forall i, j, \exists v_1, v_2((RO(i) \wedge Dep(i, j)) \rightarrow ((Dep(j, i) \leadsto DepV(i, v_1)) \wedge$	
	$(\neg Dep(j, i) \leadsto DepV(i, v_2)) \wedge (v_1 < v_2)))$	(A.3.3.1)
(2)	$\forall i, v_1, v_2((RO(i) \wedge (v_2 < v_1)) \rightarrow DepV(i, v_2)\mathbf{P}_iDepV(i, v_1))$	(A.3.1.1)
(3)	$\forall i, j \exists v_1, v_2((RO(i) \wedge Dep(i, j)) \rightarrow ((Dep(j, i) \leadsto DepV(i, v_1)) \wedge$	
	$(\neg Dep(j, i) \leadsto DepV(i, v_2)) \wedge Dep(j, i)\mathbf{P}_i \neg Dep(j, i)))$	(from (1), (2))
(4)	$\forall i, j((RO(i) \wedge Dep(i, j)) \rightarrow Dep(j, i)\mathbf{P}_i \neg Dep(j, i))$	(from (3), (BK.P.1*))
(5)	$\forall i((RO(i) \wedge Dep(i, j)) \rightarrow C_i(Dep(j, i)))$	(A.3.3.2)
(6)	$\forall i, j((RO(i) \wedge Dep(i, j)) \rightarrow \mathbf{G}_i^g(Dep(j, i)))$	(from (4), (5), (D.G.G))
(7)	$\forall i, j((RO(i) \wedge Dep(i, j) \wedge Impcomp(i, j)) \rightarrow \mathbf{G}_i^g(Dep(j, i)))$	(from (6), str. ant. QED)

We need step (4) of this proof later, so we label it as a lemma:

(L.3.3.1) $\forall i, j((RO(i) \wedge Dep(i, j)) \rightarrow Dep(j, i)\mathbf{P}_i \neg Dep(j, i))$

Note furthermore that the step from (6) to (7) was obtained by strengthening the antecedent of (6).[7] As it turns out, in step (6) we could prove a more general result: if dependency reversal is possible, organizations will seek it, regardless of whether competition is perfect or not.

We got this result because no premise hinges on the condition of imperfect competition. Yet whether perfect condition allows for dependency reversal is a different question, indeed. But is dependency reversal possible at all? Is it likely to succeed under conditions of imperfect competition? Let us have a look at the next propositions.

The next propositions, (3.3a)-(3.3c), are presented as consequences of (3.3). They specify the action of rational organizations for specific combinations of concentrated support capacity and concentrated demand on the one hand as opposed to dispersed demand on the other:

Propostion 3.3a. *When support capacity is concentrated and balanced against concentrated demands, the organizations involved will attempt to handle their dependence through contracting.*

Propostion 3.3b. *When support capacity is concentrated but demand is dispersed, the weaker organization will attempt to handle its dependence through coopting.*

Propostion 3.3c. *When support capacity is concentrated and balanced against concentrated demands, but the power achieved through contracting is inadequate, the organizations involved will attempt to coalesce.*

There is little specific justification in OIA for the particular actions sought. "Contracting", "coalescing", and "coopting" are presented as instances of dependency reversal, but they are not linked clearly to the propositions' preconditions. For example, it is left unclear why coopting is the action of choice when support capacity is concentrated but demand is dispersed in (3.3.b). As a consequence, we do not have enough information to formalize an explanation. But we present a formal representation of (3.3.a) for the record:

$$(\text{T.3.1.a}) \quad \forall i, j((O(i) \land R(i) \land Dep(i, j)$$
$$\land Impcomp(i, j) \land Impcomp(j, i)) \rightarrow \mathbf{G}_i^g(Contracted(j, i)))$$

The other two subpropositions are represented analogously.

Even though there may not much explicit reasoning supporting (3.1a) - (3.1c), the propositions themselves adumbrate the concept of dependency, especially proposition (3.3.b). In (3.3.b), we have a "weaker" organization trying to reverse dependence with respect to "stronger" organizations—stronger because they maintain alternatives. Why should such organizations accept the dependency reversal if they strive for minimal dependency? Only if dependency reversal reduces overall dependency. But it remains unclear why this should happen in the case of (3.3b), and possibly also (3.3a) and (3.3c). What does the stronger organization stand to gain from being coopted? We have no answer at this point.

The last two propositions of the chapter generalize the principle of dependency reversal while introducing a dynamic component: if constrained in relevant parts of the task environment, rational organizations are not just seeking power, but they seek to *increase* their power. Here are the propositions:

Propostion 3.4. *The more sectors in which the organization subject to rationality norms is constrained, the more power the organization will seek over remaining sectors of its task environment.*

Propostion 3.5. *The organization facing many constraints and unable to achieve power in other sectors of its task environment will seek to enlarge the task environment.*

The discursive theory does not elaborate on the special means of reinforcing the causality of power, so we have to assume that such means are available, or, at least, that rational organizations believe that they are available. We present a simple version of the theorem where we treat dependency, power and the dependent part of the task environment as dichotomous variables. This version excludes the use of a maximizing goal concept, but the proposition does not require maximization. Let S and L be constants denoting small or large values respectively, let the function $te(i)$ denote the task environment of i, let the nested expression $depp(te(i))$ evaluate to the part of i's task environment with respect to which dependence reversal is possible (call this the "malleable" part of the task environment),

and let furthermore $PowV(depp(te(i)), x)$ represent the power x of i over $depp(te(i))$:

(T.3.4) $\forall i((RO(i) \wedge DepV(i, L)) \rightarrow \mathbf{G}_i^g(PowV(depp(te(i)), L)))$

(read: for all i, if i is a rational organization, and its (overall) dependence is large, the its goal is to reach a large power-value over the part of the task environment that depends on i)

(T.3.4) is not directly derivable from the choice principles we have introduced so far, because the underlying reasoning brings in a new complication by allowing for the possibility of a kind of second-order action. As rational agents observe a relationship between the size of the malleable part of the task environment and dependence, they may seek to intensify their power over the malleable part as it shrinks. Schematically, the reasoning is as follows: if rational agents prefer ϕ to ϕ' and if χ causes ϕ', but χ-and-ψ cause ϕ, then, confronted with χ, organizations will seek ψ:

(BK.P.3) $(\phi \mathbf{P}_i \phi' \wedge (\chi \rightsquigarrow \phi') \wedge ((\chi \wedge \psi) \rightsquigarrow \phi) \wedge \chi \wedge \mathbf{C}_i(\psi)) \Rightarrow \mathbf{G}_i(\psi)$

(read: If i prefers ϕ to ϕ', and the situation χ would lead to ϕ', but the the situation χ-and-ψ would lead to ϕ, and i is in the situation χ, and ψ would not block better goals, then ψ becomes i's goal)

To derive (T.3.4) from these assumptions, we must assert a relationship between (1) the size of the malleable part of the task environment, and the organization's dependency on the one hand, and (2) the interaction of the size of the malleable part of the task environment with the compensating effects of gaining additional power over that part on the other hand.

(A.3.4.1) $\forall i(RO(i) \rightarrow (Size(depp(te(i)), S) \rightsquigarrow DepV(i, L)))$

(read: for all i, if i is a rational organization, and the size of the part of i's tasks environment that depends on i is small ($Size(depp(te(i)), S)$), then i's dependence is large (DepV(i,L)))

and

(A.3.4.2) $\forall i(RO(i) \rightarrow (Size(depp(te(i)), S) \wedge PowV(i, L)) \rightsquigarrow Dep(i, S)))$

To complete the derivation of (T.3.4) we need an additional meaning postulate, that renders (L.3.3.1) useful for the case of dichotomous variables:

$(MP.3.3.1)\ \forall i, \exists v_1, v_2(RO(i) \rightarrow ((v_2 < v_1) \wedge (DepV(i, v_2)\mathbf{P}_i DepV(i, v_1)$
$$\rightarrow DepV(i, S)\mathbf{P}_i DepV(i, L))))$$

(read: for all i there exist values v_1, v_2, such that if i is a rational organization, then, if v_2 is smaller than v_1, and v_2 is preferred as value of i's (overall)dependency to v_1, then a smaller value of i's overall dependency is preferred to a larger value)

The last provision is the usual goal-caveat:

(A.3.4.3) $\forall i((RO(i) \wedge DepV(i, L)) \rightarrow \mathbf{C}_i(PowV(depp(te(i)), L)))$

With these provisions in place, (T.3.4) is now derivable for specific organizations i upon asserting:

(A.3.4.4*) $Size(depp(te(i)), S)$

and by substituting the corresponding formulas into (BK.P.3): the consequent of (MP.3.3.1) is substituted for $\phi P \phi'$, the consequent of (A.3.4.1) is substituted for $(\chi \leadsto \phi')$, the consequent of (A.3.4.2) for $((\chi \wedge \psi) \leadsto \phi)$, the role of χ itself is played by (A.3.4.4*), and (A.3.4.3) substitutes for $\chi \wedge \mathbf{C}_i(\psi)$.

The last theorem, (3.5), is structurally identical with (3.4), except that the modified causality is now supposed to act on the size of the whole task environment, so we have as the formal version of (3.5):

(T.3.5) $\forall i((RO(i) \wedge DepV(i, L)) \rightarrow \mathbf{G}_i(Size(te(i)), L))$

To derive (T.3.5) we need the additional assumption that an organization's overall dependence is small when the dependent part of its task environment is large. This assumption is symmetric to (A.3.4.1):

(A.3.5.1) $\forall i(RO(i) \rightarrow (Size(depp(te(i)), L) \leadsto DepV(i, S)))$

The proof is analogous to the proof of T.2.1, and depends on (MP.3.3.1), (A.3.4.1), (A.3.5.1), plus a goal caveat for "$Size(depp(te(i), L))$".

This concludes the formalization of Chapter 3. As in the case of Chapter 2, there are several problems. We had a problem with the reversal of dependence: why should an organization accept dependence when there is no need to do so (Proposition (3.2) and (3.3.b)). Also, we observed a gap between the overall dependence of an organization (to be minimized), and the dependence on specific elements (to be reduced). We argued that there might be a problem in aggregating the individual sources of dependence.

OIA details dependencies in terms of single resources, but reasons in terms of the organization's overall dependence, so some aggregation of individual dependencies is assumed to take place. In the specific terms of the definition (OIA: 30), organization i can depend on agent j with respect to resource x, and in this relationship other agents k may or may not be available to replace agent j. So if an organization needs more of resource x, then it will "in proportion" depend more on resource x; if organization i receives more x from j, then it will "in proportion" depend more on j, and so forth. But we have no clarity about the *ceteris paribus* conditions that hold as the dependence on a resource changes. For example, if i comes to depend more on x, then it might come to depend less on, say, y, if the *ceteris paribus* condition covers (unchanged) output and (unchanged) productivity. If, however, the *ceteris paribus* condition covers the (unchanged) dependencies on all other resources, then, of course, the dependence on y does not decrease. Or does it? After all, "in proportion" the organization will depend relatively less on y. OIA does not provide enough information to settle these questions. In logical terms, we might have a model satisfying the definition of dependence where the overall dependence of an organization never changes

because the organization's increasing dependence on one source would imply, in proportion, less dependence on another source. Alternatively, we have models where the overall dependence varies as a function of the "distribution" of dependence over various sources. The first model cannot be the intended interpretation because much of the theory is about variations in overall dependence and about organizations seeking to minimize dependence by (re)distributing it. But changing the distribution of dependence implies that coming to depend *more* on a specific source means *less* overall dependence, so single dependencies need not add up in any straightforward way. OIA does say as much when it stipulates that power (and hence dependence) is not a zero-sum game (OIA: 31). But this does not answer the question of how to aggregate dependencies. To put it differently: if power is not a zero-sum game, which #-sum game is it?

4 Discussion

4.1 Logic as a Methodological Instrument

We did not claim that formal logic is a panacea, nor even that it is absolutely necessary for the task at hand. At each single step in the deconstruction of OIA, we could have used commonsense reasoning without resorting to a formal language. However, linking these steps would have been very difficult without the scaffold of the formal language. As Cohen and Nagel once noted: "An efficient symbolism not only exposes errors previously unnoticed, it suggests new implications and conclusions..." (Cohen and Nugel 1934) : 199. It would have taken more time to realize the different goal concepts covered by the verb phrase "organizations seek to..."; it would have been more difficult to realize gaps between macro- and micro-levels in the effects of uncertainty and dependency (e.g., when the organization is sealing off the technical core, is it reducing its own uncertainty or just that of the technical core?); we would not have felt the need to assert the (BK.P) postulates because they act as inference rules and such rules are usually not made explicit in discursive reasoning (Johnson-Laird and Byrne 1991) . It would also have been much more difficult to establish the soundness of the proofs of the theories. In sum, the formal language forces one to realize problems which are easily bypassed in natural language. ALX is not a microscope or a telescope, but it is a looking glass.

Readers may ask: why use logic—why not mathematics? There are several answers.

First, we are interested in the *logical* structure of organization theory, so we should use a *logical* instrument.

Second, what's the difference? Modern formal logic uses set theory as the meta-language, just as most other fields in mathematics do. The difference is in paying specific attention to the formal restrictions on the syntax, and having a formalized notion of logical consequence (especially important in a logical deconstruction).

When the question ("why not math") is raised, however, it is usually with some familiar techniques in mind, such as linear algebra and calculus. The semantic restrictions on these mathematics are stronger than in formal logic; informally speaking, it is difficult to do this math without using numbers and defining total functions. As a consequence, a formalization

by means of the traditional techniques requires a level of domain knowledge that the target theory may not provide—one reason for the theory not to be a mathematical one. Since the semantic restrictions in formal logic are weaker, formal logic may be more flexible in grasping the tentative theories that are typical of OT, OB, and many other fields in the social sciences.

Third, the pragmatic answer: we have developed ALX, and now we are trying to use it. We are in the position of the child who gets a hammer and then finds everything needs hammering. But the metaphor works both ways. How do we know that theories don't need hammering? The context for applying logic is fairly opaque, so there is no reliable way to decide in advance whether a particular logic does work. In short: under norms of rationality, organizational theorists should seek to apply logic—even if they don't know in advance whether success is guaranteed.

To repeat: logic is not a panacea. More recent research about the role of logic in cognitive processes has shown that its role is limited, more limited than logic's founders would have thought (Johnson-Laird and Wason 1977; Johnson-Laird and Byrne 1991). Reasoning, including theoretical reasoning, rarely follows the syntactic path of formal logic with its emphasis on declarative premises, formal inference rules, and derivations. Instead, reasoning is done "in models"; the reasoner has an intuitive model of the domain and uses his knowledge about the domain plus all his background knowledge when reasoning about this model. Logic comes into play when the reasoner may go wrong; there is no guarantee that the intuitive model is correct, and the likelihood that a model is correct goes down as the model itself becomes "more theoretical", more of a guess about uncharted terrain. Relying under such circumstances upon ones intuition is dangerous, since it means relying on ones prejudice; additional instruments for checking a model's correctness are needed. Formal logic is just one of these instruments. Empirical testing is another—and both instruments may complement each other.

The claims of this paper are modest. Naturally, we hope that logic can get us further, but the present study is using logic only as a tool for the clarification of the structure of an organization theory. Looking at other fields, one sees that logic might go much further. It may provide the scaffold for a canonical axiomatization of a theory (the standard-example is Euclidean Geometry), establish the theory's consistency, contingency, the independence of the axioms, parsimony, and other desirable features of a theory.

Efforts at logical formalization are quite rare. One possible reason is that they are exacting, tiresome, and raise questions that may take a long time to answer.[8] On the other hand, spending more time on theoretical construction—rather than speeding a set of hypotheses to empirical testing, as is the rule today—may ultimately produce more solid theory. There is a growing understanding that social science research may not produce the cumulativity that is widely hoped for. Perhaps this is not only a matter of data analysis; theories with deficient logical structure are not a good basis for scientific progress, in part, because they are not a good basis for data analysis to begin with.

4.2 Action Logic

First Order Logic is usually identified as *the* logic by the general public, and mainstream epistemology assumed for a long time that FOL would be sufficient to adequately formal-

ize any theory, including social science theories (Salancik and Leblebici 1993). The discovery of opaque contexts generated by attitudes together with other technical problems in knowledge representation led to the development of various nonstandard logics, including logics specialized for representing actions. We developed a new action logic primarily for two technical reasons: (1) the established formalisms have goals as primitive operators, and this leads to fairly nasty side-effects; (2) the available action logics feature interaction between the primitive modal operators (i.e., primitive operators appear in the logical axioms of other primitive operators). This entails ontological assumptions that we wanted to avoid since they preempt an unbiased knowledge representation of a theory.

This paper does not demonstrate all aspects of ALX.3's power. There is no real attempt to write data structures for multi-agent interaction, since there was no need to do so; in the first part of OIA, the organization is usually the only agent, and other agents (the agents j in the formulas about counter-dependence) play only a passive role. Also, we could almost do without the use of particular action modalities. It would have complicated the formulas to have made these modalities explicit,[10] but added little to the formal argument. On the other hand, we did need the action modalities in the definition of accessibility, and in the goal definitions. We would expect that other target theories may require a different, possibly more intense use of action modality, especially if they differentiate between degrees of accessibility (the ease with which something can be done) or if they reason in terms of particular sequences of actions. Our conjecture is that action theories of OIA's kind (roughly speaking: action theories as delineated in (Parsons 1937)) are structured by the interplay of possible and impossible actions. For example, from a bird's-eye view one might say that "organizations are trying to *reduce* uncertainty". But when push comes to shove and one is forced "to explain" what this "means", one has to go into the microstructure of "reducing uncertainty", to concede that uncertainty is not *directly* accessible, and to specify a chain of more primitive actions that, hopefully, reduce uncertainty. It seems quite natural that the analysis of an action in terms of micro-actions can be applied recursively, and it might be that the recursion has no natural endpoint. Still, such a recursion might structure a theory of action, and hence the further development of such a theory.

4.3 Did We Learn Anything About Thompson?

In formalizing Thompson's text, we had to realize that the theory has a serious coherence problem. Organizations are said to seek a minimization of *uncertainty* on the one hand but minimize *cost* on the other. Organizations cannot attain both goals if costs are incurred in search for certainty, or if uncertainty is risked in the search for lower cost (think of just-in-time-delivery). A goal conflict must result.

There are several ways to handle this problem. One alternative, that would neutralize goal conflicts, would use the conceptual machinery of Simon's paper on organizational goals (Simon 1964). Simon pointed out that all goal statements come with an implicit list of *ceteris paribus* conditions ("constraints" in Simon's language): whenever a goal is singled out, this is done under the implicit assumption that many other constraints are respected, constraints that may assume the role of goals in other contexts. In short: goal statements are always contextual. For example, cost is to be minimized provided that uncertainty does not reach

unsatisficing levels, and vice versa. One can generalize this idea to arbitrary goals by employing the notion of satisficing, and specify that no goal should violate its surrounding constraints by moving into unsatisficing terrain. This specification, in turn, can be added to the C-waivers. As a side-effect, the C-waivers would include a provision against "over"-zealous choices and the need for starring (A.2.2.3) and (A.4.1.2) would disappear. More formally, a potential goal ϕ should not be believed to lead to an unsatisfactory situation ρ. For a potential goal ϕ, this stipulation can be expressed as follows:

$$\neg \mathbf{B}_i \exists \rho((\phi \rightsquigarrow \rho) \wedge \neg \mathbf{S}_i(\rho))$$

and this stipulation can be added to the definition of the C-waivers.

Although this solution should "work" in a conceptual way, it has drawbacks. We have no definition for the S-operator, only one weak meaning postulate. The reason is that "satisficing" is a procedural addition to the original conceptualization of bounded rationality: its meaning depends, among other things on the agent's history (Simon 1987). To have a definition of, or stronger meaning postulates for, the S-operator, we would have to generalize over such histories, and OIA does not provide enough information to do so. As a consequence, our use of "satisficing" may provide an escape clause that may endanger the theory's empirical content.[11]

Another important semantic problem arose with the aggregation of effects across organizations, such as uncertainty, and dependency. For example, OIA details dependence at the level of single resources but reasons at the level of the overall organization: how do we get from the specific dependency on a resource to the organization's overall dependence? We can make the aggregation step if dependence is additive, but the "logic" of dependency reversal seems to require that it is not, and a related problem comes up in the aggregation of uncertainty. Again, a complete discussion of these problems is beyond the scope of this paper. But one can try to make sure that unintended interpretations of the theory are barred.

Regarding uncertainty, one would have to state that reducing the specific uncertainty of the technical core does reduce the overall uncertainty of the organization:

$$\forall i, \exists u_1, u_2, u_3, u_4 (RO(i) \rightarrow ((u_1 < u_2) \wedge (u_3 < u_4) \wedge (UV(tc(i), u_1) \rightsquigarrow UV(i, u_3)) \\ \wedge (UV(tc(i), u_2) \rightsquigarrow UV(i, u_4)))$$

Having this assumption, one would no longer have to duplicate the preference statements regarding uncertainty: reducing the uncertainty of the technical core will appear as a means to the end of reducing overall uncertainty.

As to the relation between overall dependence and dependence on a singular source, one has to bridge a second aggregation gap; in addition, one has to take into account the non-zero-sum-nature of power. In analogy to the last formula, one could relate the dependency on a specific source to the overall dependency of the organization, and say that, *ceteris paribus,* reducing the dependency on a specific resource reduces the overall dependency. Note, however, that this puts a fairly heavy burden on the rationality assumption of orga-

nizational agents and relies on the fact that our ceteris paribus conditions (implicit in the constraints on the closest world function) are relatively weak.

The non-zero-sum nature of power appears in several guises. It comes up first in the discussion of the "prestige-proposition" (3.2). One solution that might work in the case of "prestige" is to drop the assumptions that all other agents in the task environment are rational; after all, other agents need not be organizations, and arbitrary individual agents are not held "to be rational, or else . . ."[12] As it turns out, there is no need to drop the rationality assumption, since it was never made; agents j in the context of proposition (3.2) were never qualified as rational.[13]

In the case of the other propositions, however, one cannot rely on the irrationality of other agents since those other agents are organizations; in addition, one might not want to rely on their irrationality in case of (3.2), since this would partition the task environment into rational organizations and potentially irrational non-organizations.

The minimum requirement is, indeed, that dependency reversal is enticing enough for other organizations j. So if other organizations accept the dependency reversal, then this should, *ceteris paribus*, reduce their overall dependency. The underlying semantics appears to be as follows: being dependent on a dependent source induces less uncertainty than being dependent on an independent source, since reciprocal dependence is stabilized by the reciprocal threat of retaliation. As a consequence, organizations may experience less uncertainty by relying on a smaller number of dependent partners.

As noted, we do not pretend to have a final solution. A more substantial solution would have to address the subtleties of reciprocal dependence, and this would require bringing in the conceptual apparatus of the "norms of reciprocity" (Gouldner 1960), or of transaction costs (Williamson 1975), or of trust theories (Breton and Wintrobe 1982). The challenge here would be to simplify and/or unify these approaches until they fit the conceptual apparatus of OIA.

4.4 Other Recent Efforts

The last couple of years have seen a renewed effort to apply formal languages in organization theory and beyond. G. Salancik and H. Leblebici are using a script-formalism to analyze organizational design (Salancik and Leblebici 1993); H. Gazendam is using BNF (a specification language for computer program) to formalize Fayol's classical theory of organizations (Gazendam 1993); K. Manhart is using the Suppes/Sneed-formalism to formalize Attribution Theory (Manhart 1994); Péli, Masuch, Bruggman and others used FOL to formalize the theory of organizational ecology (Péli and Masuch 1994a; Péli, G. et al., 1994b)[14]; L. Pólos is formalizing OIA in a newly developed default logic based on situation semantics (Pólos 1994); and K. Devlin and D. Rosenberg are working on a formalization of ethnomethodology in another variant of situation semantics (Devlin 1994; Devlin and Rosenberg 1994).

All this work produces similar results. Formal logic, when relentlessly applied, has both destructive and constructive effects. In each case, problems in the logical construction of the target theory are found which spawn new ways to "repair the theory", and to provide a better logical structure for it.

5 Conclusions: ALX in Action

The paper presented a multi-agent action logic especially designed for social science theories and applied it to a classical organization theory, J.D. Thompson's *Organizations in Action* (OIA). The working hypothesis was that formal logic draws attention to some finer points in the logical structure of a theory that are easily neglected in the discursive reasoning typical of organization theory (and many other fields in the social sciences). Representing the propositions of Chapters 2–4 of OIA we do find a variety of smaller and larger problems, especially in the attempt of organizations to pursue incompatible goals and the conceptualization of dependence. By putting ALX to work, we explored its expressive power and found it satisfactory for the task at hand. With its four primitive operators, ALX provides flexibility in defining new operators and allows for a fairly straightforward modelling of actions and attitudes as we encountered them in OIA.

We expect at least three objections: (1) Readers may argue that they knew all along that organization theories were shaky. Now, if they are right, and organization theories are, indeed, shaky, our reply would be: why didn't you do anything about it, or, if you did, why didn't you succeed? The primary mode of theory improvement in the last 30 years or so has been empirical testing. Apparently, then, empirical testing by itself is not enough. (2) Readers may argue that organization theory has "progressed" and that we should have looked at the recent literature. The problem is that real cumulativity in building theories is difficult to achieve if the working material—previous theories—don't provide a solid basis. (3) Readers may argue that the specific nature of organization theories (or perhaps of the social sciences in general) will never allow for more logical precision. Such a claim is falsifiable by counterexamples, and we would claim that the studies cited in the previous section do provide such counterexamples. Perhaps, this study does so, too.

6 Suggestions for Further Research

There is a renewed interest in applying logic in theory building. The last major effort, by logical positivism, did not get very far, possibly because there was no clarity about the limits to the expressive power of FOL, no tradition in formal semantics, and no computational support; everything had to be done by hand, as it were. The conditions are better now. Further research should possibly be in several direction.

First, one has to develop more experience in applying formal logics to a variety of theories; the experimental basis at present is small. If a broader basis of results support the working hypothesis that discursive theories in the social sciences provide room for logical improvement, then the research community at large may feel encouraged to accept the challenge of formal logic, just as it has accepted mathematical statistics in the past.

Second, there is room for improvement of the logical instruments. In case of ALX, for example, the addition of modal time operators is desirable, and also more refinement in the constraints on the closest world function. There are alternative approaches. Pólos, for example, argues that the apparent goal conflict in OIA is due to the practice of default reasoning, and developed a default logic to cope with the problem.

Third, more flexible computational support is needed. Peli et al. can use a strong theorem prover for FOL which allows them to work on larger sets of formulas and perform meta-analyses, such as consistency tests. The work for the present paper was done by hand, but there are experimental theorem provers for modal logics and a theorem prover for ALX is in the works.

Acknowledgements

A Appendix I: ALX3

A.1 Syntax

The language has the following primitive symbols:

(1) For each natural number $n(\geq 1)$, a countable set of n-place predicate letters, PRE_n, which we write as $p_i, p_j, \ldots$
(2.1) A countable set of regular variables, $RVAR$, which we write as $x, x_1, y, z, \ldots$
(2.2) A countable set of action variables, $AVAR$, which we write as $a, a_1, b, \ldots$
(2.3) A countable set of agent variables, $AGVAR$, which we write as $i, i_1, j, \ldots$
(3.1) A countable set of regular constants, $RCON$, which we write as $c, c_1, c_2, \ldots$
(3.2) A countable set of actions constants, $ACON$, which we write as $ac, ac_1, ac_2, \ldots$
(3.3) A countable set of agent constants, $AGCON$, which we write as $ag, ag_1, ag_2, \ldots$
(4) The symbols $\neg$(negation), $\wedge$(conjunction), $\mathbf{B}$(belief), $\exists$ (existential quantifier), P(preference), $\rightsquigarrow$(conditional), ;(sequence), $\cup$(choice), and parentheses: $\langle, \rangle$, (, and).

We assume that the above sets are disjoint so their intersections are empty.

Definition 1 (Variable) The set of variables VAR is defined as follows:

$$VAR = RVAR \cup AVAR \cup AGVAR.$$

Definition 2 (Constant) The set of constants CON is defined as follows:

$$CON = RCON \cup ACON \cup AGCON.$$

Definition 3 (Term) The set of terms $TERM$ is defined as follows:

$$TERM = VAR \cup CON.$$

Definition 4 (Action term) The set of action terms $ATERM$ is defined as follows:

$$ATERM = AVAR \cup ACON.$$

Definition 5 (Agent term) The set of agent terms $AGTERM$ is defined as follows:

$$AGTERM = AGVAR \cup AGCON.$$

In the following, we use $t, t_1, \ldots$, to denote terms, $a, a_1, \ldots$, to denote action terms, $i, j, \ldots$, to denote agent terms if that does not cause any ambiguity.

Definition 6 (Atom) The set of atomic formulae $ATOM$ is defined as follows:

$$ATOM =_{df} \{p(t_1, t_2, \ldots, t_n) \ : \ p \in PRE_n, t_1, t_2, \ldots, t_n \in TERM\}.$$

Definition 7 (Action) The set of action expression $ACTION$ is defined recursively as follows:

- $a \in ATERM, i \in AGTERM \Rightarrow a_i \in ACTION.$
- $a, b \in ACTION \Rightarrow (a; b), (a \cup b) \in ACTION.$

Definition 8 (Formula) The set of formulae FML is defined recursively as follows:

- $ATOM \subseteq FML.$
- $\phi \in FML \Rightarrow \neg\phi \in FML.$
- $\phi, \psi \in FML \Rightarrow (\phi \wedge \psi) \in FML.$
- $\phi \in FML, x \in VAR \Rightarrow (\exists x\phi) \in FML.$
- $\phi \in FML, a \in ACTION \Rightarrow (\langle a \rangle \phi) \in FML.$
- $\phi, \psi \in FML \Rightarrow (\phi \rightsquigarrow \psi) \in FML.$
- $\phi, \psi \in FML, i \in AGTERM \Rightarrow (\phi P_i \psi) \in FML.$
- $\phi \in FML, i \in AGTERM \Rightarrow \mathbf{B}_i\phi \in FML.$

Define $\perp$ as $\phi \wedge \neg\phi$ for an arbitrary ϕ, and $[a]\phi$ as $\neg\langle a \rangle\neg\phi$. Define the boolean connectives $\{\vee, \rightarrow, \leftrightarrow\}$, and the truth constant $\top$ from the given boolean connectives in the usual way. $\forall x(\varphi)$ is defined as $\neg\exists x(\neg\varphi)$.

A.2 Semantics

Definition 9 (ALX3 model) We call $M = \langle Object, PA, AGENT, W, cw, >, \Re, \mathcal{B}, I \rangle$ an ALX3 model, if

- O is a set of objects,
- PA is a set of primitive actions,

- $AGENT$ is a set of agents,
- W is a set of possible worlds,
- $cw : W \times \mathcal{P}(W) \longrightarrow \mathcal{P}(W)$ is a closest world function,
- $>: AGENT \rightarrow \mathcal{P}(\mathcal{P}(W) \times \mathcal{P}(W))$ is a function which assigns a comparison relation for preferences to each agent,
- $\mathcal{R} : AGENT \times PRIMITIVE\text{-}ACTION \rightarrow \mathcal{P}(W \times W)$ is a function which assigns an accessibility relation to each agent and each primitive action,
- $\mathcal{B} : AGENT \rightarrow \mathcal{P}(W \times W)$ is a function that assigns an accessibility relation for beliefs to each agent,
- I is a pair $\langle I_P, I_C \rangle$, where I_P is a predicate interpretation function which assigns to each n-place predicate letter $p \in PRE_n$ and each world $w \in W$ a set of n tuples $\langle u_1, \ldots, u_n \rangle$, where each of the $u_1, \ldots, u_n$ is in $D = O \cup PA \cup AGENT$, called a domain, and I_C is a constant interpretation function which assigns to each regular constants $c \in RCON$ an object $d \in O$, assigns to each action constant $ac \in ACON$ a primitive action $a_p \in PA$, and assigns to each agent constant $g \in AGCON$ an agent $a_g \in AGENT$,

and if the model satisfies the following conditions:

(i) the closest world function cw satisfies (CS1)-(CS5):

(CS1) : $cw(w, X) \subseteq X$.

(CS2) : $w \in X \Rightarrow cw(w, X) = \{w\}$.

(CS3) : $cw(w, X) = \varnothing \Rightarrow cw(w, Y) \cap X = \varnothing$.

(CS4) : $cw(w, X) \subseteq Y and cw(w, Y) \subseteq X \Rightarrow cw(w, X) = cw(w, Y)$.

(CS5) : $cw(w, X) \cap Y \neq \varnothing \Rightarrow cw(w, X \cap Y) \subseteq cw(w, X)$.

(ii) the comparison relation (for each agent) satisfies the following conditions:

For each agent $i \in AGENT$,

(NORM) :$(\varnothing \not<_i X), (X \not<_i \varnothing)$.

where $>_i = > (i)$.

(TRAN) :$cw(w, X \cap \bar{Y}) >_i cw(w, Y \cap \bar{X})$ and $cw(w, y \cap \bar{Z}) >_i cw(w, Z \cap \bar{Y})$
$\Rightarrow cw(w, X \cap \bar{Z}) >_i cw(w, Z \cap \bar{X})$,
where $\bar{X} = W - X$.

(iii) the accessibility relation (for each agent) is serial and transitive, namely,

(SEB) :$\forall w \exists w'(\langle w, w' \rangle \in \mathcal{B}_i)$,
where $\mathcal{B}_i = \mathcal{B}(i)$.

(TRB) : $\langle w, w' \rangle \in \mathcal{B}_i$ and $\langle w', w'' \rangle \in \mathcal{B}_i \Rightarrow \langle w, w'' \rangle \in \mathcal{B}_i$

(CS1)-(CS5) are standard constraints for the closest world function in the semantic model of conditionals. (NORM) and (TRAN) constrain the semantics for the preference relation. (SEB) and (TRB) turn the accessibility relation for beliefs into a weak S4 structure.

Definition 10 (Valuation of variables) A valuation of variables v in the domain D of an ALX3 model M is a mapping which assigns to each variable $x \in VAR$ an element $d \in D$ such that $v(x) \in O$, $v(a) \in PA$, and $(i) \in AGENT$ for any $x \in RVAR, a \in AVAR$, and $i \in AGVAR$.

Definition 11 (Valuation of terms) For an ALX3 model $M = \langle Object, PA, AGENT, W, cw, >, \mathfrak{R}, \mathfrak{B}, I \rangle$ and a valuation of variables v, a valuation of terms v_I is a function that assigns to each term $t \in TERM$ an element in the domain D, which is defined as follows:

$$t \in CON \Rightarrow v_I(t) = I_C(t);$$
$$t \in VAR \Rightarrow v_I(t) = v(t).$$

Suppose that v is a valuation of variables, d is an element of the domain, and x is a variable. We use the notation $v(d/x)$ to denote the valuation of variables which assigns the same values to the variables as does v except that it assigns the value d to x. Moreover, we use the notation V_D to denote the set of valuations of variables in the domain D.

Definition 12 (Accessibility relations for actions) Define an accessibility relation $R^{a'}$ in a model $M = \langle Object, PA, AGENT, W, cw, >, \mathfrak{R}, \mathfrak{B}, I \rangle$ and a valuation v for each action $a' \in ACTION$ as follows.

- $a \in ATERM, i \in AGTERM \Rightarrow R^{a_i} = \mathfrak{R}(v_I(a), v_I(i))$,
- $a, b \in ACTION \Rightarrow R^{(a;b)} = R^a \circ R^b$
$$= \{\langle w, w' \rangle \in W \times W : (\exists w_1 \in W)(R^a w w_1 \text{ and } R^b w_1 w')\},$$
- $a, b \in ACTION \Rightarrow R^{(a \cup b)} = R^a \cup R^b.$

Definition 13 (Meaning function) Let FML be as above and let $M = \langle AGENT, W, cw, >, \mathfrak{R}, \mathfrak{B}, I \rangle$ be an ALX3 model and let v be a valuation of variables in the domain D. The meaning function $[\![\ ]\!]_M^v : FML \to \mathcal{P}(W)$ is defined as follows:

$$[\![p(t_1, \ldots, t_n)]\!]_M^v = \{w \in W : \langle v_I(t_1), v_I(t_2), \ldots, v_I(t_n) \rangle \in I_P(p, w)\} \text{ where } p \in PRE_n.$$

$$[\![\neg \phi]\!]_M^v = W \setminus [\![\phi]\!]_M^v.$$

$$[\![\phi \wedge \psi]\!]_M^v = [\![\phi]\!]_M^v \cap [\![\psi]\!]_M^v.$$

$$[\![\exists x \phi]\!]_M^v = \{w \in W : (\exists d \in D)(w \in [\![\phi]\!]_M^{v(d/x)})\}.$$

$$[\![\langle a \rangle \phi]\!]_M^v = \{w \in W : (\exists w' \in W)(R^a w w' \text{ and } w' \in [\![\phi]\!]_M^v)\}.$$

$$[\![\phi \rightsquigarrow \psi]\!]_M^v = \{w \in W : cw(w, [\![\phi]\!]_M^v) \subseteq [\![\psi]\!]_M^v\}.$$

$$[\![\phi P_i \psi]\!]_M^v = \{w \in W : cw(w, [\![\phi \wedge \neg \psi]\!]_M^v) >_{v_l(i)} cw(w, [\![\psi \wedge \neg \phi]\!]_M^v)\}.$$

$$[\![\mathbf{B}_i \phi]\!]_M^v = \{w \in W : (\forall w')(\langle w, w'\rangle \in \mathcal{B}_{v_l(i)} \Rightarrow w' \in [\![\phi]\!]_M^v)\}.$$

The forcing and satisfiable relations are defined as usual.

Definition 14 (ALX3 inference system) Let ALX3S be the following set of axioms and rules of inference.

(BA)   *all tautologies of the first order logic*

(A1)	$\langle a\rangle\bot$	$\leftrightarrow$	$\bot.$
(A2)	$\langle a\rangle(\phi \vee \psi)$	$\leftrightarrow$	$\langle a\rangle\phi \vee \langle a\rangle\psi.$
(A3)	$\langle a;b\rangle\phi$	$\leftrightarrow$	$\langle a\rangle\langle b\rangle\phi.$
(A4)	$\langle a \cup b\rangle\phi$	$\leftrightarrow$	$\langle a\rangle\phi \vee \langle a\rangle\langle b\rangle\phi.$
(AU)	$[a]\forall x\phi$	$\rightarrow$	$\forall x[a]\phi.$

(ID)	$\psi \rightsquigarrow \psi.$		
(MPC)	$(\psi \rightsquigarrow \phi)$	$\rightarrow$	$(\psi \rightsquigarrow \phi).$
(CC)	$(\psi \rightsquigarrow \phi) \wedge (\psi \rightsquigarrow \phi')$	$\rightarrow$	$\psi \rightsquigarrow (\phi \wedge \phi').$
(MOD)	$(\neg\psi \rightsquigarrow \psi)$	$\rightarrow$	$(\phi \rightsquigarrow \psi).$
(CSO)	$((\psi \rightsquigarrow \phi) \wedge (\phi \rightsquigarrow \psi))$	$\rightarrow$	$((\psi \rightsquigarrow \chi) \leftrightarrow (\phi \rightsquigarrow \chi))$
(CV)	$((\psi \rightsquigarrow \phi) \wedge \neg(\psi \rightsquigarrow \neg\chi))$	$\rightarrow$	$((\psi \wedge \chi) \rightsquigarrow \phi).$
(CS)	$(\psi \wedge \phi)$	$\rightarrow$	$(\psi \rightsquigarrow \phi).$

(CEP)	$\phi P_i \psi$	$\leftrightarrow$	$(\phi \wedge \neg\psi)P_i(\neg\phi \wedge \psi).$
(N)	$\neg(\bot P_i \phi),$		$\neg(\phi P_i \bot).$
(TR)	$(\phi P_i \psi) \wedge (\psi P_i \chi)$	$\rightarrow$	$(\phi P_i \chi).$

(PC)	$(\phi P_i \psi)$	$\rightarrow$	$\neg((\phi \wedge \neg\psi)\neg(\phi \wedge \neg\psi))$
			$\wedge \neg((\psi \wedge \neg\phi)\neg(\psi \wedge \neg\phi)).$
(KB)	$\mathbf{B}_i\phi \wedge \mathbf{B}_i(\phi \rightarrow \psi)$	$\rightarrow$	$\mathbf{B}_i\psi.$
(DB)	$\neg\mathbf{B}_i\bot.$		
(4B)	$\mathbf{B}_i\phi$	$\rightarrow$	$\mathbf{B}_i\mathbf{B}_i\phi.$

(BFB)	$\forall x\mathbf{B}_i\phi$	$\rightarrow$	$\mathbf{B}_i\forall x\phi.$

(MP)	$\vdash \phi \,\&\, \vdash \phi \rightarrow \psi$	$\Rightarrow$	$\vdash \psi.$
(G)	$\vdash \phi$	$\Rightarrow$	$\vdash \forall x\phi.$
(NECA)	$\vdash \phi$	$\Rightarrow$	$\vdash [a]\phi.$
(NECB)	$\vdash \phi$	$\Rightarrow$	$\vdash \mathbf{B}_i\phi.$
(MONA)	$\vdash \langle a\rangle\phi \,\&\, \vdash \phi \rightarrow \psi$	$\Rightarrow$	$\vdash \langle a\rangle\psi.$
(MONC)	$\vdash \phi \rightsquigarrow \psi \,\&\, \vdash \psi \rightarrow \psi'$	$\Rightarrow$	$\vdash \phi \rightsquigarrow \psi'.$
(SUBA)	$\vdash (\phi \leftrightarrow \phi')$	$\Rightarrow$	$\vdash (\langle a\rangle\phi) \leftrightarrow (\langle a\rangle\phi').$
(SUBC)	$\vdash (\phi \leftrightarrow \phi') \,\&\, \vdash (\psi \leftrightarrow \psi')$	$\Rightarrow$	$\vdash (\phi \rightsquigarrow \psi) \leftrightarrow (\phi' \rightsquigarrow \psi').$
(SUBP)	$\vdash (\phi \leftrightarrow \phi') \,\&\, \vdash (\psi \leftrightarrow \psi')$	$\Rightarrow$	$\vdash (\phi P_i \psi) \leftrightarrow (\phi' P_i \psi').$

B Appendix II: Symbols and Formulas

1. Modal operators

$\rightsquigarrow$ = conditional
$\langle a_i \rangle$ = action operator
$\mathbf{A}_i$ = accessibility
$\mathbf{B}_i$ = belief
$\mathbf{BA}_i$ = badness
$\mathbf{C}_i$ = caveat
$\mathbf{DA}_i$ = direct accessibility
$\mathbf{G}_i$ = goal
$\mathbf{G}_i^{bc}$ = best choice goal
$\mathbf{G}_i^{bc(\Phi)}$ = best choice goal w.r.t. the dimension Φ
$\mathbf{G}_i^g$ = good goal
$\mathbf{G}_i^s$ = satisficing goal
$\mathbf{GO}_i$ = goodness
$\mathbf{K}_i$ = knowledge
$\mathbf{P}_i$ = preference
$\mathbf{PO}_i$ = element of preference order
$\mathbf{S}_i$ = satisfication

2. Predicate symbols

$AA(x)$ = x is anticipated and adapted
$Bal(i, j)$ = the input/output relationship between i and j is balanced
$Bu(x)$ = x is buffered
$C(i, v)$ = the value of i's cost is v
$CC(i, v)$ = the value of i's coordination cost is v
$CC(i, v, MIN)$ = v is the minimal value of i's coordination cost
$Contracted(i, j)$ = j is contracted by i
$Ct(i, x)$ = x corresponds to i's technology
$Dep(i, j)$ = i depends on j
$DepV(i, v)$ = i's dependence value is v
$DepV(i, v, MIN)$ = v is the minimal dependence value of i
$Fuo(i)$ = all components of i are fully occupied
$Impcomp(i, j)$ = i is in a position of imperfect competition w.r.t j
$Llt(i)$ = i has a long-linked technology
$MA(i)$ = i maintains alternatives
$O(i)$ = i is an organization
$Partof(i, j)$ = j is part of i
$Pow(i, j)$ = i has power over j

$PowV(i, x) = x$ is the value of i's power
$Pr(i) = i$ has prestige
$R(i) = i$ is rational
$Rat(x) = x$ is being protected by rationing
$RO(i) = i$ is a rational organization
$Size(i, S) = i$'s size is small
$Sm(x) = x$'s input and output are smoothed
$So(i) = i$ is sealed off
$U(x) = x$ is subjected to uncertainty
$UV(i, x) = x$ is the uncertainty value of i
$Vi(i, x) = x$ technologically corresponds to i

3. Function and Constant symbols

$cc(i) = $ cost of acquiring recources of i
$depp(te(i)) = $ dependent part of i's task environment
$dom(i) = $ domain of i
$L = $ large
$lrc(i) = i$'s least-reducible component
$S = $ small
$tc(i) = i$'s technical core

4. Definitions

(D.KN) $\mathbf{K}_i(\phi) \overset{\text{def}}{\Leftrightarrow} \mathbf{B}_i(\phi) \wedge \phi$

(D.A) $\mathbf{A}_i(\phi) \overset{\text{def}}{\Leftrightarrow} \mathbf{DA}_i(\phi) \vee (\mathbf{DA}_i(\psi) \wedge (\psi \rightsquigarrow \phi))$

(D.GO) $\mathbf{GO}_i(\phi) \overset{\text{def}}{\Leftrightarrow} (\phi \mathbf{P}_i \neg \phi)$

(D.BA) $\mathbf{BA}_i(\phi) \overset{\text{def}}{\Leftrightarrow} (\neg \phi \mathbf{P}_i \phi)$

(D.PO) $\mathbf{PO}_i(\phi) \overset{\text{def}}{\Leftrightarrow} (\phi \mathbf{P}_i \rho) \vee (\rho \mathbf{P}_i \phi)$

(D.C) $\mathbf{C}_i(\phi) \overset{\text{def}}{\Leftrightarrow} \neg \mathbf{B}_i(\neg \mathbf{A}_i(\phi) \wedge \exists \psi (\mathbf{A}_i(\psi) \wedge (\psi \mathbf{P}_i \phi) \wedge (\phi \rightsquigarrow \neg \mathbf{A}_i(\psi))))$

(D.G.G) $\mathbf{G}_i^g(\phi) \overset{\text{def}}{\Leftrightarrow} \mathbf{GO}_i(\phi) \wedge \mathbf{C}_i(\phi)$

(D.G.S) $\mathbf{G}_i^s(\phi) \overset{\text{def}}{\Leftrightarrow} \mathbf{S}_i(\phi) \wedge \mathbf{C}_i(\phi)$

(D.G.BC) $\mathbf{G}_i^{bc}(\phi) \overset{\text{def}}{\Leftrightarrow} (\phi \mathbf{P}_i \rho) \wedge \mathbf{C}_i(\phi)$

(D.G.CBC) $\mathbf{G}_i^{bc(\Phi)}(\Phi(i, x)) \overset{\text{def}}{\Leftrightarrow} (\Phi(i, x) \mathbf{P}_i \rho) \wedge \forall y (\Phi(i, y) \mathbf{P}_i \Phi(i, x) \rightarrow \neg \mathbf{B}_i(\mathbf{A}_i(\Phi(i, y))))$

(D.C.CBC) $\mathbf{C}_i^{bc(\Phi)}(\Phi(i, x) \overset{\text{def}}{\Leftrightarrow} \forall y (\Phi(i, y) \mathbf{P}_i \Phi(i, x) \rightarrow \neg \mathbf{B}_i(\mathbf{A}_i(\Phi(i, y))))$

(D.RO) $\forall i (RO(i) \leftrightarrow (R(i) \wedge O(i)))$

(D.POW) $\forall i, j (Pow(i, j) \leftrightarrow Dep(j, i))$

(D.MinDep) $\forall i, v(RO(i) \rightarrow (DepV(i, v, MIN) \leftrightarrow \mathbf{G}_i^{bc(DepV)}(DepV(i, v))))$
(D.4.1.a.1) $\forall i((RO(i) \wedge Llt(i) \wedge Ct(i, cc(i))) \rightarrow (Vi(i, cc(i)) \leftrightarrow Partof(i, cc(i))))$
(D.MinCC) $\forall i, v(RO(i) \rightarrow (CC(i, v, MIN) \leftrightarrow \mathbf{G}_i^{bc(CC)}(CC(i, v))))$

5. Assumptions

(A.2.1.1) $\forall i(RO(i) \rightarrow \mathbf{BA}_i(U(tc(i))))$
(A.2.1.2) $\forall i(RO(i) \rightarrow (\neg So(tc(i)) \rightsquigarrow (U(tc(i)))))$
(A.2.1.3) $\forall i(RO(i) \rightarrow (So(tc(i)) \rightsquigarrow (\neg U(tc(i)))))$
(A.2.1.4) $\forall i(RO(i) \rightarrow ((\neg So(tc(i)) \rightsquigarrow U(tc(i))) \wedge (So(tc(i)) \rightsquigarrow \neg U(tc(i)))))$
(A.2.1.5) $\forall i(RO(i) \rightarrow \mathbf{C}_i(So(tc(i))))$
(A.2.2.1) $\forall i, u_1, u_2((RO(i) \wedge (u_1 < u_2)) \rightarrow UV(tc(i), u_1)\mathbf{P}_iUV(tc(i), u_2))$
(A.2.2.2) $\forall i, \exists u_1, u_2(RO(i) \rightarrow ((u_1 < u_2) \wedge (Bu(tc(i)) \rightsquigarrow UV(tc(i), u_1))$
$\wedge(\neg Bu(tc(i)) \rightsquigarrow UV(tc(i), u_2))))$
(A.2.2.3*) $\forall i(RO(i) \rightarrow \mathbf{C}_i(Bu(tc(i))))$
(A.2.3.2) $\forall i, \exists u_1, u_2(RO(i) \rightarrow ((u_1 < u_2) \wedge (Sm(tc(i))UV \rightsquigarrow (tc(i), u_1))$
$\wedge(\neg Sm(tc(i)) \rightsquigarrow UV(tc(i), u_2))))$
(A.2.3.3*) $\forall i(RO(i) \rightarrow \mathbf{C}_i(Sm(tc(i))))$
(A.2.4.2) $\forall i, \exists u_1, u_2(RO(i) \rightarrow ((u_1 < u_2) \wedge (AA(tc(i)) \rightsquigarrow UV(tc(i), u_1))$
$\wedge(\neg AA(tc(i)) \rightsquigarrow UV(tc(i), u_2))))$
(A.2.4.3*) $\forall i(RO(i) \rightarrow \mathbf{C}_i(AA(tc(i))))$
(A.2.5.1*) $(RO(i) \wedge \neg(\mathbf{S}_i(Bu(tc(i)) \wedge Sm(tc(i)) \wedge AA(tc(i)))))$
(A.2.5.2) $\forall i, \exists u_1, u_2(RO(i) \rightarrow ((u_1 < u_2) \wedge (Rat(tc(i)) \rightsquigarrow UV(tc(i), u_1))$
$\wedge(\neg Rat(tc(i)) \rightsquigarrow UV(tc(i), u_2))))$
(A.2.5.3*) $\forall i(RO(i) \rightarrow \mathbf{C}_i(Rat(tc(i))))$
(A.3.1.1) $\forall i, v_1, v_2(RO(i) \wedge (v_1 < v_2) \rightarrow (DepV(i, v_1)\mathbf{P}_iDepV(i, v_2)))$
(A.3.1.2) $\forall i, v(RO(i) \rightarrow \mathbf{K}_i\neg\mathbf{DA}_i(DepV(i, v, MIN)))$
(A.3.1.3) $\forall i, \exists v(RO(i) \rightarrow (MA(i) \rightsquigarrow DepV(i, v, MIN)))$
(A.3.1.4) $\forall i(RO(i) \rightarrow \mathbf{B}_i(\mathbf{DA}_i(MA(i))))$
(A.3.1.5) $\forall i(RO(i) \rightarrow \mathbf{C}_i(MA(i)))$
(A.3.2.1) $\forall i, \exists v_1, v_2(RO(i) \rightarrow ((v_1 < v_2) \wedge (Pr(i) \rightsquigarrow DepV(i, v_1))$
$\wedge(\neg Pr(i) \rightsquigarrow DepV(i, v_2))))$
(A.3.2.2) $\forall i(RO(i) \rightarrow \mathbf{C}_i(Pr(i)))$
(A.3.2.3) $\forall i, \exists v(RO(i) \rightarrow (Pr(i) \rightsquigarrow DepV(i, v, MIN)))$
(A.3.3.1) $\forall i, j, \exists v_1, v_2(RO(i) \wedge Dep(i, j) \rightarrow ((v_1 < v_2) \wedge (Dep(j, i) \rightsquigarrow DepV(i, v_1))$
$\wedge(\neg Dep(j, i) \rightsquigarrow DepV(i, v_2))))$
(A.3.3.2) $\forall i((RO(i) \wedge Dep(i, j)) \rightarrow \mathbf{C}_i(Dep(j, i)))$
(A.3.4.1) $\forall i(RO(i) \rightarrow (Size(depp(te(i)), S) \rightsquigarrow DepV(i, L)))$
(A.3.4.2) $\forall i(RO(i) \rightarrow (Size(depp(te(i)), S) \wedge PowV(i, L)) \rightsquigarrow Dep(i, S)))$
(A.3.4.3) $\forall i((RO(i) \wedge DepV(i, L)) \rightarrow \mathbf{C}_i(PowV(depp(te(i)), L)))$
(A.3.4.4*) $Size(depp(te(i)), S)$
(A.3.5.1) $\forall i(RO(i) \rightarrow (Size(depp(te(i)), L) \rightsquigarrow DepV(i, S)))$

(A.3.5.2) $\forall i, x(RO(i) \rightarrow \mathbf{C}_i(Size(depp(te(i)), x)))$

(A.4.1.1) $\forall i, \exists u_1, u_2(RO(i) \rightarrow ((u_2 < u_1) \wedge (\neg Partof(i, cc(i)) \rightsquigarrow Uv(i, u_1))$
$\wedge (Partof(i, cc(i)) \rightsquigarrow Uv(i, u_2))))$

(A.4.1.2*) $\forall i, x(RO(i) \rightarrow \mathbf{C}_i(Partof(i, cc(i))))$

(A.4.2.1) $\forall i, j((RO(i) \wedge Partof(i, j)) \rightarrow (Fuo(j) \leftrightarrow Fuo(lrc(i))))$

(A.4.2.2) $\forall i, \exists v_1, v_2(RO(i) \rightarrow ((v_2 < v_1) \wedge C(i, v_2)\mathbf{P}_i C(i, v_1)))$

(A.4.2.3) $\forall i, \exists v_1, v_2(RO(i) \rightarrow ((v_2 < v_1) \wedge (\neg Fuo(lrc(i)) \rightsquigarrow C(i, v_1)) \wedge (Fuo(lrc(i)) \rightsquigarrow C(i, v_2))))$

(A.4.2.4) $\forall i(RO(i) \rightarrow \mathbf{C}_i(Fuo(i)))$

(A.4.2.5*) $\mathbf{S}_i(Size(dom(i)))$

(A.4.3.1) $\forall i, j, k((RO(i) \wedge Partof(i, j) \wedge Partof(i, k) \wedge Bal(j, k))$
$\rightarrow (\mathbf{S}_i(Size(dom(i))) \leftrightarrow Fuo(i)))$

(A.4.3.2) $\forall i(RO(i) \rightarrow \mathbf{C}_i(Fuo(i)))$

(A.5.1.1) $\forall i, v_1, v_2(RO(i) \wedge (v_2 < v_1) \rightarrow CC(i, v_2)\mathbf{P}_i CC(i, v_1))$

6. Background knowledge

(BK.P.1*) $((\phi \mathbf{P}_i \phi') \wedge (\psi \rightsquigarrow \phi) \wedge (\psi' \rightsquigarrow \phi')) \Rrightarrow \psi \mathbf{P}_i \psi'$

(BK.U1) $\forall i, u_1, u_2((RO(i) \wedge UV(i, u_1)) \wedge UV(i, u_2)) \rightarrow (u_1 = u_2))$

(BK.U2) $\forall i, \exists u(RO(i) \rightarrow UV(i, u))$

(BK.P.2) $\mathbf{G}_i(\phi) \wedge (\psi \rightsquigarrow \phi) \wedge \neg \mathbf{DA}_i(\phi) \wedge \mathbf{C}_i(\psi) \Rrightarrow \mathbf{G}_i(\psi)$

(BK.P.2.1) $\mathbf{G}_i^{bc(\Phi)}(\Phi(i, v)) \wedge (\psi \rightsquigarrow \Phi(i, v, MIN)) \wedge \neg \mathbf{DA}_i(\Phi(i, v, MIN)) \wedge \mathbf{C}_i(\psi) \Rrightarrow \mathbf{G}_i^g(\psi)$

(BK.P.2.2) $\forall x, y((x < y) \rightarrow \Phi(i, x)\mathbf{P}_i \Phi(i, y)) \rightarrow \exists v(\Phi(i, v, MIN))$

(BK.P.3) $(\phi \mathbf{P} \phi' \wedge (\chi \rightsquigarrow \phi') \wedge ((\chi \wedge \psi) \rightsquigarrow \phi) \wedge \chi \wedge \mathbf{C}_i(\psi)) \Rrightarrow \mathbf{G}_i(\psi)$

7. Meaning postulates

(MP.S.1) $\mathbf{S}_i(\phi) \Rrightarrow \mathbf{PO}_i(\phi)$

(MP.3.3.1) $\forall i, \exists d_1, d_2(RO(i) \rightarrow ((d_2 < d_1) \wedge (DepV(i, d_2)\mathbf{P}_i DepV(i, d_2)$
$\rightarrow DepV(i, S)\mathbf{P}_i DepV(i, L))))$

8. Theorems

(T.2.1) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(So(tc(i))))$

(T.2.2) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(Bu(tc(i))))$

(T.2.3) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(Sm(tc(i))))$

(T.2.4) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(AA(tc(i))))$

(T.2.5) $\forall i(RO(i) \wedge \neg(\mathbf{S}_i(Bu(tc(i)) \wedge Sm(tc(i)) \wedge AA(tc(i)))) \rightarrow \mathbf{G}_i^{bc}(Rat(tc(i))))$

(T.3.1) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(MA(i)))$

(T.3.2) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(Pr(i)))$

(T.3.1*) $\forall i \exists v(RO(i) \rightarrow \mathbf{G}_i^{bc(DepV)}(DepV(i, v)))$

(T.3.3) $\forall i, j((RO(i) \wedge Dep(i, j) \wedge mpcomp(i, j)) \rightarrow \mathbf{G}_i^g(Dep(j, i)))$

(T.3.4) $\forall i((RO(i) \wedge DepV(i, L)) \rightarrow \mathbf{G}_i^g(PowV(depp(te(i)), L)))$

(T.3.5) $\forall i((RO(i) \wedge DepV(i, L)) \rightarrow \mathbf{G}_i(Size(depp(te(i)), L))))$

(T.4.1) $\forall i, x(RO(i) \rightarrow \mathbf{G}_i^g(Partof(i, cc(i))))$

(T.4.1.a) $\forall i, x((RO(i) \wedge Llt(i) \wedge Ct(i, cc(i))) \rightarrow \mathbf{G}_i^g(Vi(i, cc(i))))$

(T.4.2) $\forall i((RO(i) \wedge \mathbf{S}_i(Size(dom(i))) \wedge \neg Fuo(i)) \rightarrow \mathbf{G}_i^g(Fuo(lrc(i))))$

(T.4.3) $\forall i, j, k((RO(i) \wedge Partof(i, j) \wedge Partof(i, k) \wedge Bal(j, k) \wedge \neg \mathbf{S}_i(Size(dom(i)))$
$\wedge \neg Fuo(i)) \rightarrow \mathbf{G}_i^s(\mathbf{S}_i(Size(dom(i)))))$

(T.5.1) $\forall i(RO(i) \rightarrow \mathbf{G}_i^{bc(CC)}(CC(i, v)))$

9. Lemmas

(L.2.1.1) $\forall i(RO(i) \rightarrow \mathbf{GO}_i(\neg U(tc(i))))$

(L.2.2.1) $\forall i(RO(i) \rightarrow \mathbf{GO}_i(Bu(tc(i))))$

(L.2.3.1) $\forall i(RO(i) \rightarrow \mathbf{GO}_i(Sm(tc(i))))$

(L.2.4.1) $\forall i(RO(i) \rightarrow \mathbf{GO}_i(AA(tc(i))))$

(L.3.1.1) $\forall i, \exists v(RO(i) \rightarrow \mathbf{G}_i^{bc(DepV)}(DepV(i, v)))$

(L.3.3.1) $\forall i, j((RO(i) \wedge Dep(i, j)) \rightarrow Dep(j, i)\mathbf{P}_i \neg Dep(j, i))$

(L.4.2) $\forall i(RO(i) \rightarrow \mathbf{G}_i^g(Fuo(i)))$

10. Relations between theorems and their premises

(T.2.1):   (A.2.1.1), (D.BA), (D.GO), (A.2.1.4), (A.2.1.5), (BK.P.1*), (D.G.G)

(T.2.2):   (A.2.2.1), (A.2.2.2), (BK.P.1*), (D.GO), (A.2.2.3*), (D.G.G)

(T.2.3):   (A.2.2.1), (A.2.3.2), (BK.P.1*), (D.GO), (A.2.3.3*), (D.G.G)

(T.2.4):   (A.2.2.1), (A.2.4.2), (BK.P.1*), (D.GO), (A.2.4.3*), (D.G.G)

(T.2.5):   (A.2.5.1*), (A.2.2.1), (A.2.5.2), (BK.P.1*), (A.2.5.3*), (D.GO),
              (BK.P.1*), (D.G.G)

(T.3.1):   (A.3.1.1), (BP.P.2.2), (D.MinDep), (A.3.1.3), (A.3.1.2), (A.3.1.5), (BP.P.2.1)

(T.3.1*):   (A.3.1.1), (BP.P.2.2), (D.MinDep)

(T.3.2):   (A.3.1.1), (BP.P.2.2), (D.MinDep), (A.3.2.3), (A.3.1.2), (A.3.2.2), (BP.P.2.1*)

(T.3.3):   (A.3.3.1), (A.3.1.1), (BK.P.1*), (A.3.3.2), (D.G.G)

(T.3.4):   (MP.3.3.1), (MP.3.3.1), (BK.P.3), (A.3.4.1), (A.3.4.2), (A.3.4.3), (A.3.4.4*)

(T.3.5):   (A.3.5.1), (BK.P.1*), (A.3.5.2)

(T.4.1):   (A.4.1.1), (A.2.2.1), (BK.P.1*), (A.4.1.2*), (D.G.G)

(T.4.1.a):   (D.4.1.a.1), (A.4.1.1), (A.2.2.1), (BK.P.1*), (A.4.1.2*), (D.G.G)

(T.4.2):   (A.4.2.1), (A.2.2.1), (A.4.2.2), (BK.P.1*), (A.4.2.4), (D.G.G), (A.4.2.5*)

(T.4.3):   (A.4.2.1), (A.4.3.1), (BK.P.1*), (A.4.3.2), (D.G.G)

(T.5.1):   (A.5.1.1), (BP.P.2.2), (D.MinCC)

(L.2.1.1):   (A.2.1.1), (D.BA), (D.GO)

(L.2.2.1):   (A.2.2.1), (A.2.2.2), (BK.P.1*), (D.GO)

(L.2.3.1):   (A.2.2.1), (A.2.3.2), (BK.P.1*), (D.GO)

(L.2.4.1):   (A.2.2.1), (A.2.4.2), (BK.P.1*), (D.GO)

(L.3.1.1):   (A.3.1.1), (BP.P.2.2), (D.MinDep)
(L.3.3.1):   (A.3.3.1), (A.3.1.1), (BK.P.1∗)
(L.4.2):   (A.4.2.1), (A.2.2.1), (A.4.2.2), (BK.P.1∗), (A.4.2.4), (D.G.G)

Notes

1. Extensionality means that the meaning of an expression coincides with its "extension" (the set of all instances that are its reference). As a consequence, an expression such as "Jones seeks a unicorn" does not make sense unless unicorns exist. Or take the more topical example: "Organizations seek certainty". In an extensional context this statement is senseless unless certainty is attainable. Nonstandard logics of the kind of ALX are *intensional* in making a difference between sense and reference by using the notion of "possible worlds" e.g., worlds where unicorns might exist or organizations might not be exposed to uncertainty.

2. This section provides a very brief sketch of FOL. For more detailed accounts, the reader is referred to Appendix 2 of Péli et al, "A Logical Approach to Organizational Ecology: Formalizing the Inertia-Fragment in First-Order Logic" in the *American Sociological Review* 59: 571-593 (1994), or to standard textbooks, such as (Gamut 1991) or (Barwise and Etchemandy 1990). For a elaborate formal account, the reader is referred to (Huang, Mausch, and Polos).

3. Note the family resemblance with the concept in contingency theory, where, roughly speaking, the adequacy of an organizational property is "contingent" on a given environment; note also the difference.

4. We provide "reads" for formulas that may appear difficult at first sight and hope they'll appear more readable at second sight.

5. To use this principle in the case of restricted best choices, we have to specialize it to:

$$(\text{BK.P.2.1}) \quad \mathbf{G}_i^{bc(\Phi)}(\Phi(i, v)) \wedge (\psi\Phi(i, v, MIN)) \wedge \neg\mathbf{DA}_i(\Phi(i, v, MIN)) \wedge \mathbf{C}_i(\psi) \Rrightarrow \mathbf{G}_i^{g}(\psi)$$

   ... and in order to use it, we have to make sure that the Φ-minimum does exist:

$$(\text{BK.P.2.2}) \quad \forall x, y((x < y) \rightarrow \Phi(i, x)\mathbf{P}_i\Phi(i, y)) \rightarrow \exists v(\Phi(i, v, MIN)).$$

6. Task environment is defined as the set of those agents in the environment on whom the organization is (potentially) dependent.

7. Strengthening the antecedent means adding new conjuncts to the antecedent of a conditional formula $\phi \rightarrow \psi$. Each conjunct specializes the extension of the antecedent to a subset of the original extension denoted by the antecedent. Because the "$\rightarrow$" is extensional, this means that the strengthened condition will be true provided the original formula was true: if the formula is made true by (the extension of) the original set, it will be made true by (the extensions of) the original set's subsets. So if $\phi \rightarrow \psi$ is true, then $(\phi \wedge \chi) \rightarrow \psi$ is true as well. This fact is also called "monotony" of the conditional. Monotony is at odds with a causal interpretation of the "$\rightarrow$", and is one of the reasons for introducing the causal arrow.

8. Think of the question of whether Euclid's fifth postulate is independent; that question was not settled until the 19th century.

9. Such as the closure of goals under implication (e.g., if having healthy teeth is a goal, then toothache becomes a goal, if maintaining healthy teeth requires painful dental treatment).

10. By, say, writing $\langle buffers_i\rangle Bu(i)$ rather than $Bu(i)$.

11. As W. Baumol already pointed out in his critique of Cyert and March's *Behavioral Theory of the Firm* (Baumol 1971).

12. Although they are usually supposed to be rational in OIA's second part that deals with organizational behavior.

13. On the other hand, these agents j prevent an important simplification of the formal apparatus. All other agents are said to be rational organizations; so, if we restrict ourselves to the universe of rational organisations, we

could drop the antecedent $\forall i(RO(i))$ from all formulas where it occurs, and assert once and for all that all agents in our domain are rational organizations.

14. Péli et al. chose Organizational Ecology because it has been explicitly developed as an extensional, *non*-action theory.

References

Barwise, J. and J. Etchemendy (1990), *The Language of First-Order Logic*. Stanford, CA: CSLI 23.

Baumol, W. J. (1971), "On Rhe Behavioral Rheory of the Firm," in R. Marris and A. Wood (Eds.) *The Corporate Economy*, Cambridge, MA: Harvard University Press, 118–143.

Blumer, H. (1969), *Symbolic Interactionism: Perspective and Methods*. Englewood Cliffs, NJ: Prentice Hall.

Breton, A. and R. Wintrobe (1982), *The Logic of Bureaucratic Conduct*. Cambridge: Cambridge University Press.

Bruggeman, J. (1994), *Niche Width Theory Reappraised*, CCSOM Working Paper, 94–117.

Cohen, M.D., J.G. March and J. P. Olsen (1972), "A Garbage Can Model of Organizational Choicew" *Administrative Science Quarterly* 17, 1–25.

Cohen, M. R. and E. Nagel (1934), *An Introduction to Logic and Scientific Method*, New York.

Cohen, P. R. and H. J. Levesque (1987), Persistence, Intention and Commitment, in M. P. Georgeff and A. L. Lansky (Eds.) *Proceedings of the 1986 Workshop on Reasoning About Actions and Plans*, Morgan Kaufmann Publishers, San Mateo, CA, 297–340.

Cohen, P. R. and H. J. Levesque (1990), "Intention is Choice with Commitment," *Artificial Intelligence* 42, 213–261.

Devlin, K. (1994),"Situation Theory and Social Structure," in M. Masuch and L. Pólos (Eds.) *Knowledge Representation and Reasoning Under Uncertainty: Logic at Work*. Berlin: Springer, 197–237.

Devlin, K. and D. Rosenberg,"Situation Theory and Cooperative Action," in *Situation Theory and its Applications*, 3 CSLI lecture notes, forthcoming.

French, S. (1988), *Decision Theory, An Introduction to the Mathematics of Rationality*. Ellis Horwood Limited.

Gazendam, H.W.M. (1993), *Variety Controls Variety: On the Use of Organization Rheories in Information Management*. Groningen: Wolters-Noordhoff.

Gamut, L.T.F. (1991), *Logic, Language, and Meaning*. Chicago: University of Chicago Press.

Giddens, A. (1979), *Central Problems in Social Theory: Action, Structures, and Contradiction in Cocial Analysis*. Berkeley: University of California Press.

Glance, N.S. and B.A. Huberman (1994), "Social Dilemmas and Fluid Organization," in K.M. Carley and M. Prietula (Eds.), *Computational Organization Theory*, Hillsdale, NJ: Lawrence Erlbaum Associates, 217–240.

Gouldner, A.W. (1960), "The Norm of Reciprocity," *American Sociological Review* 35.

Grandori, A. (1987), *Perspectives on Organization Theory*. Cambridge, MA: Ballinger.

Habermas, J. (1984), *The Theory of Communicative Action*. Boston: Beacon Press.

Hannan, M.T. and J. Freeman (1977), "The Population Ecology of Organizations," *American Journal of Sociology* 82, 929–964.

Hannan, M.T. and J. Freeman (1989), *Organizational Ecology*. Cambridge, MA: Harvard University Press.

Harel, D. (1984), "Dynamic Logic," in D. Gabbay and F. Guenthner, (Eds.) *Handbook of Philosophical Logic*, Vol.II, D. Reidel 497–604.

Huang, Z. and M. Masuch (1991), *Reasoning About Action: A Comparative Survey*, CCSOM Research Report, 91–37.

Huang, Z., M. Masuch and L. Pólos (1992), *A Preference Logic for Rational Actions*. CCSOM Research Report, 92–45.

Huang, Z., M. Masuch and L. Pólos (1996), "ALX, An Action Logic for Agents with Bounded Rationality," *Artificial Intelligence* 82, 75–127.

Huang, Z. and M. Masuch (1993), *ALX3, A Multi-Agent Action Logic*. CCSOM Working Paper, 93–102.

Johnon-Laird, P.N. and P.C. Wason (1977), *Thinking: Readings in Cognitive Science*. Cambridge: Cambridge University Press.

Johnon-Laird, P.N. and R.M.J. Byrne (1977), *Deduction*. Hove: Lawrence Erlbaum Associates.

Lindenberg, S. (1991), "Die Methode der abnehmenden Abstraktion: Theoriegesteuerte Analyse und empirischer Gehalt,", in H. Esser and K. Troitzsch (Eds.) *Modellierung sozialer Prozesse.* Bonn: Informationszentrum Sozialwissenschaften, 29–78.

Luhmann, N. (1982), *The Differentiation of Society.* New York: Columbia University Press.

Manhart, K. (1994), "Strukturalistische Theorienkonzeption in den Sozialwissenschaften," *Zeitschrift für Soziologie* **23**, 111–128.

March, J.G. (1976), "The Technology of Foolishness," in J.G. March and J.P. Olsen (Eds) *Ambiguity and Choice in Organizations,* Bergen, Norway: Universitetsforlaget, 69–81.

March, J.G. and J.P. Olsen (1986), "Garbage Can Models of Decision Making in Organizations," in J.G. March and R. Weissinger-Baylon (Eds) *Ambiguity and Command,* Marshfield, MA: Pitman, 11–53.

March, J.G. and H.A. Simon (1958), *Organizations.* New York: Wiley.

Masuch, M. (1991), *Formalization of Thompson's Organization in Action.* CCSOM Research Report, 91–32.

Masuch, M. (1992), "Artificial Intelligence in Organization and Management Theory," in M. Masuch and M. Warglien (Eds), *Artificial Intelligence in Organization and Management Theory. Models of Distributed Intelligence.* New York and Amsterdam: North-Holland.

Moore, R.C. (1985), *A Formal Theory for Knowledge and Action.* CSLI Report 85–31, Stanford University.

Montague, R. (1974), *Formal Philosophy.* New Haven: Yale University Press.

Mintzberg, H. (1979), *The Structuring of Organizations.* Englewood Cliffs, NJ: Prentice Hall.

Padgett, J.F. (1980), "Managing Garbage Can Hierarchies," in *Administrative Science Quarterly* 25, 583–604.

Parsons, T. (1937), *The Structure of Social Action.* Glencoe, IL: Free Press.

Parsons, T. (1960), *Structure and Process in Modern Societies.* New York: The Free Press of Glencoe.

Péli, G. and M. Masuch (1994), "The Logic of Propagation Strategies," *Academy of Management Proceedings,* forthcoming.

Péli, G., J. Bruggeman, M. Masuch, and B. Ó Nualláin (1994), "A Logical Approach to Organizational Ecology: Formalizing the Inertia-Fragment in First Order Logic," *American Sociological Review* 59, 571–593.

Pólos, L. (1993), "Information States in Situation Semantics," CCSOM Research Report, 93–98.

Pólos, L. (1993), "Updated Situation Semantics," *Journal of Symbolic Logics.*

Pólos, L. (1994), "Scientific Rules and Empirical Generalization: Towards a Situational Theory of Theory Building," CCSOM Report, 94–116.

Rao, A. S. and Georgeff, M. P. (1991), "Modelling Rational Agents Within a BDI-Architecture," in J. Allen, R. Fikes, and E. Sandewall (Eds) *Proceedings of the Second International Conference on Principles of Knowledge Representation and Reasoning,* San Mateo, CA: Morgan Kaufmann, 473–484.

Salancik, G. R. and H. Leblebici (1993), "Grammars for Theories of Organization," *Workshop on Mathematical Organization Theory,* Chicago IL.

Salmon, W. (1990), *Four Decades of Scientific Explanation.* Minneapolis, MN: University of Minnesota Press.

Schutz, A. (1967), *The Phenomenology of the Social World.* Evanston, IL: Northwestern University Press.

Simon, H.A. (1955), "A behavioral Model of Rational Choice," *Quarterly Journal of Economics* 69, 99–118.

Simon, H. A. (1964), "On the Concept of Organizational Goal," *Administrative Science Quarterly* 9, 1–22.

Simon, H.A. (1987), "Bounded Rationality," in J. Eatwell, et al. (Eds.) *The New Palgrave,* London: Macmillan Press.

Stalnaker, R. (1968), "A Theory of Conditionals," *Studies in Logical Theory, American Philosophical Quarterly* 2, 98–122.

Thompson, J.D. (1967), *Organizations in Action, Social Science Bases of Administrative Theory.* New York: Mc Graw-Hill.

Von Wright, G.H. (1963), *The Logic of Preference.* Edinburgh.

Williamson, O.E. (1975), *Markets and Hierarchies: Analysis and Antitrust Implications.* New York: Free Press.

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