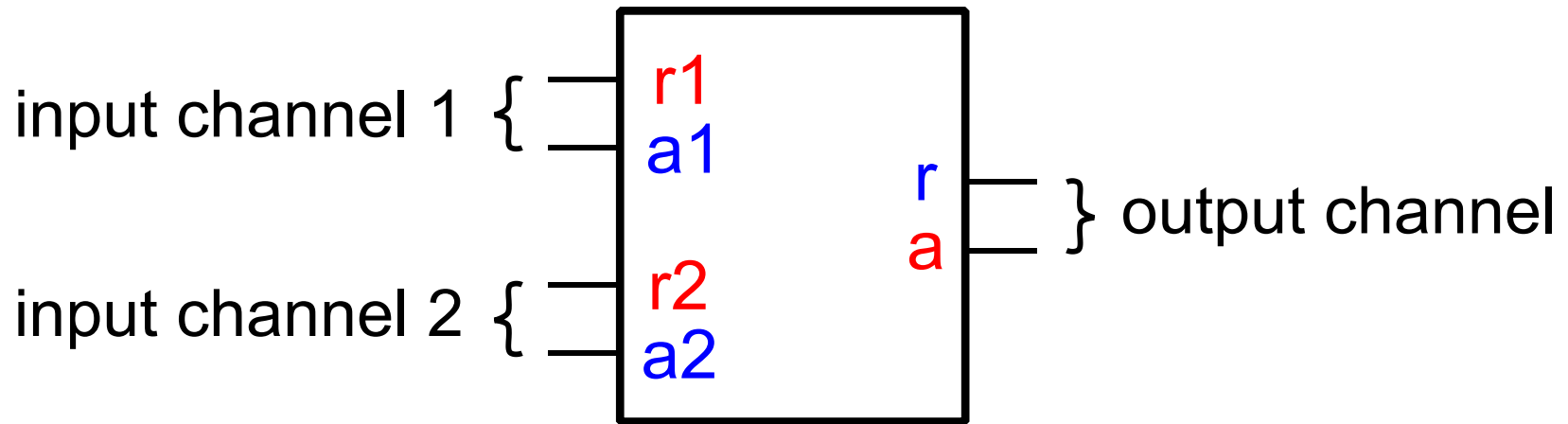


Opportunistic Merge Element

Andrey Mokhov, Victor Khomenko,
Danil Sokolov, Alex Yakovlev

Merge Element



Purpose: merge independent requests

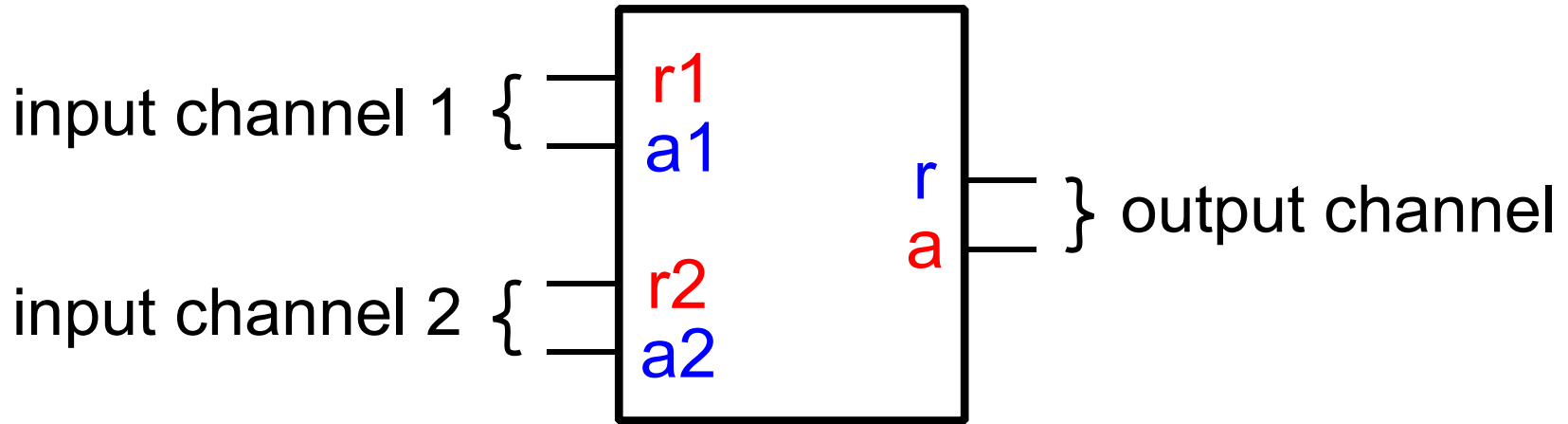
Example: count the total number of requests

Property: requests are never lost, $I_1 + I_2 = O$

Requires arbitration

- between requests
- better outside the critical path

Opportunistic Merge Element



Purpose: merge independent requests, *bundling closely arriving requests together*

Example: respond to an alarm (two sensors)

Property: $\max(I_1, I_2) \leq O \leq I_1 + I_2$

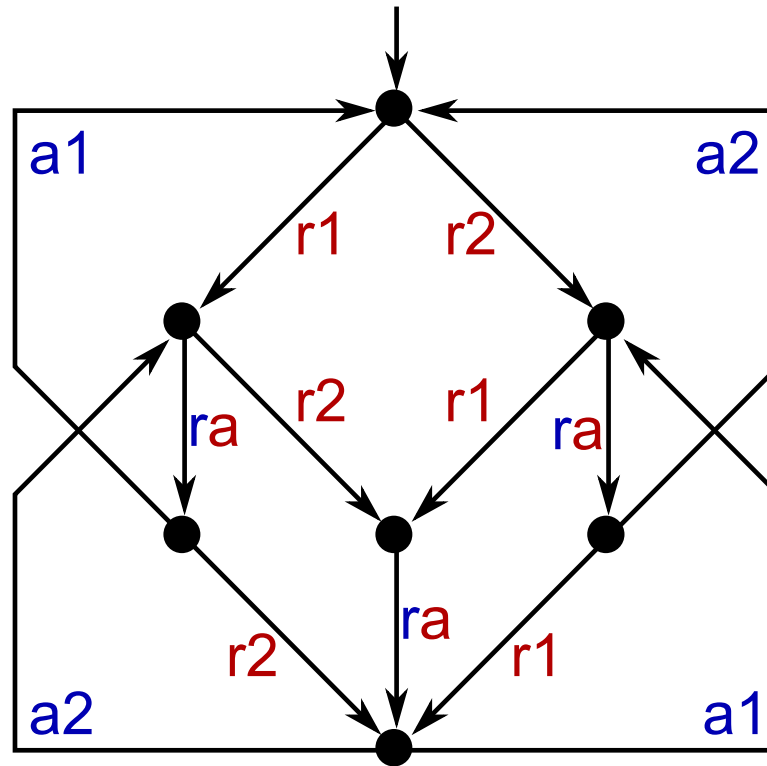
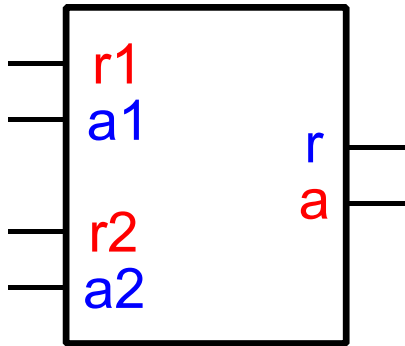
OMs in the real world



Our motivation:
**on-chip power
management**

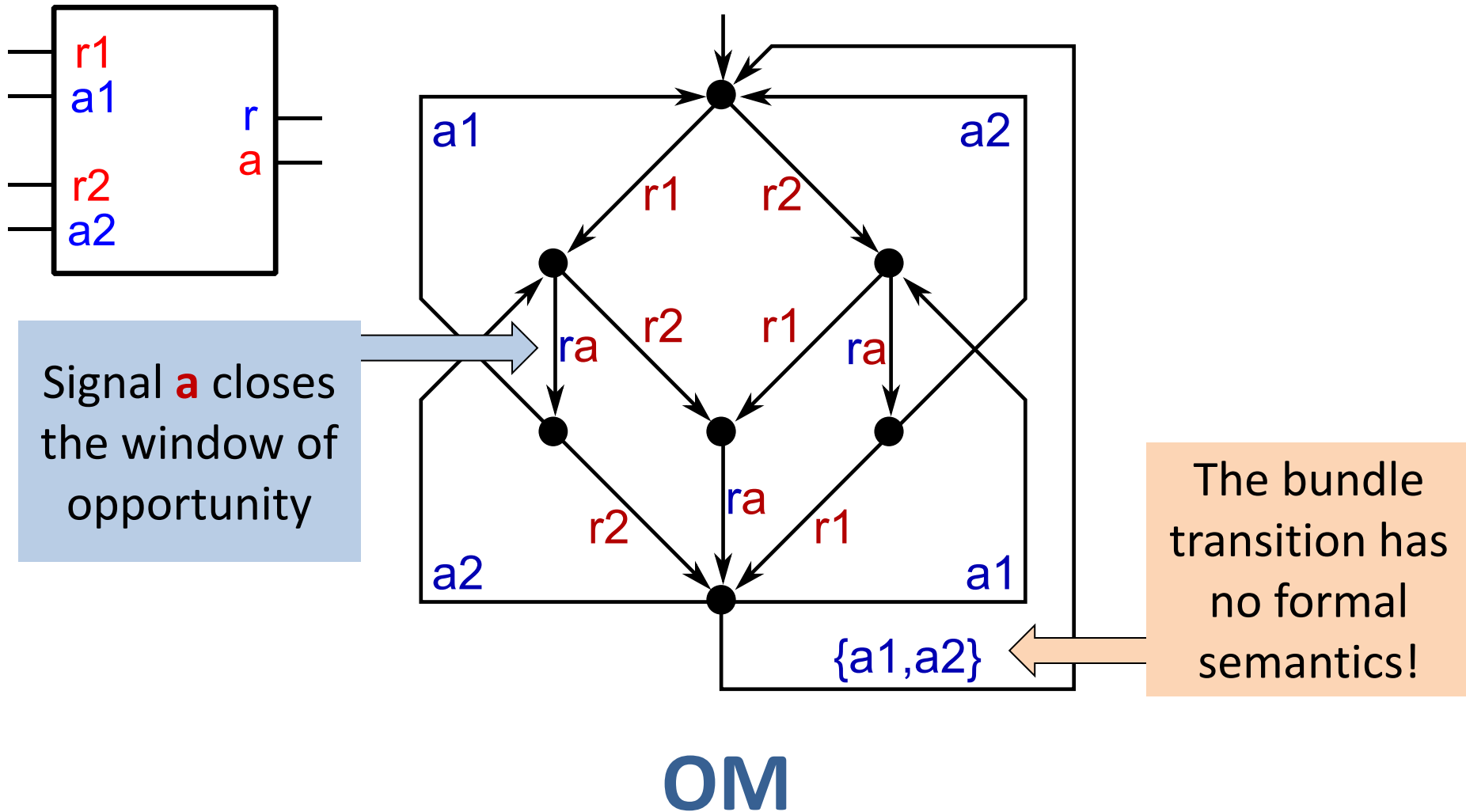


Conceptual specification



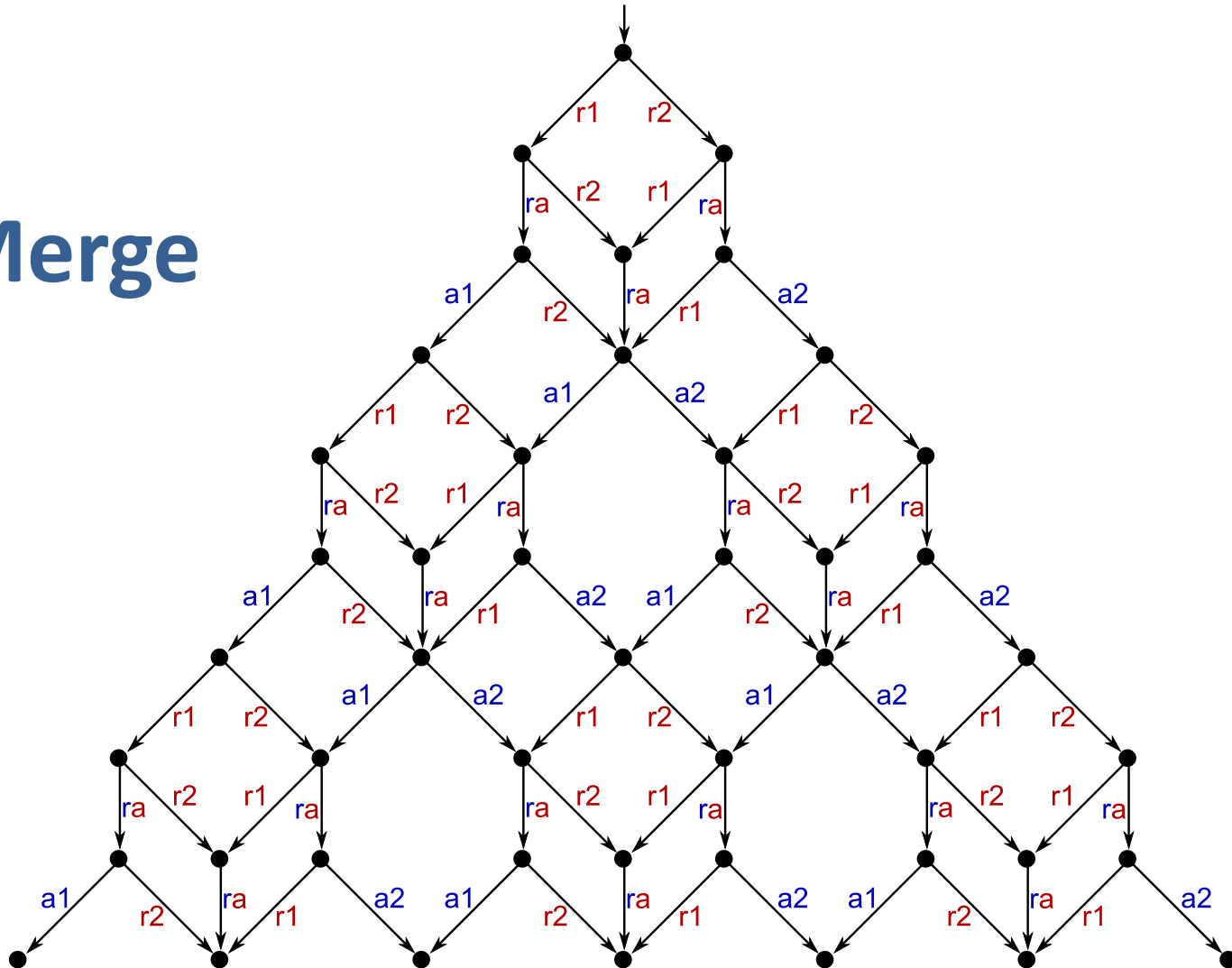
Merge

Conceptual specification



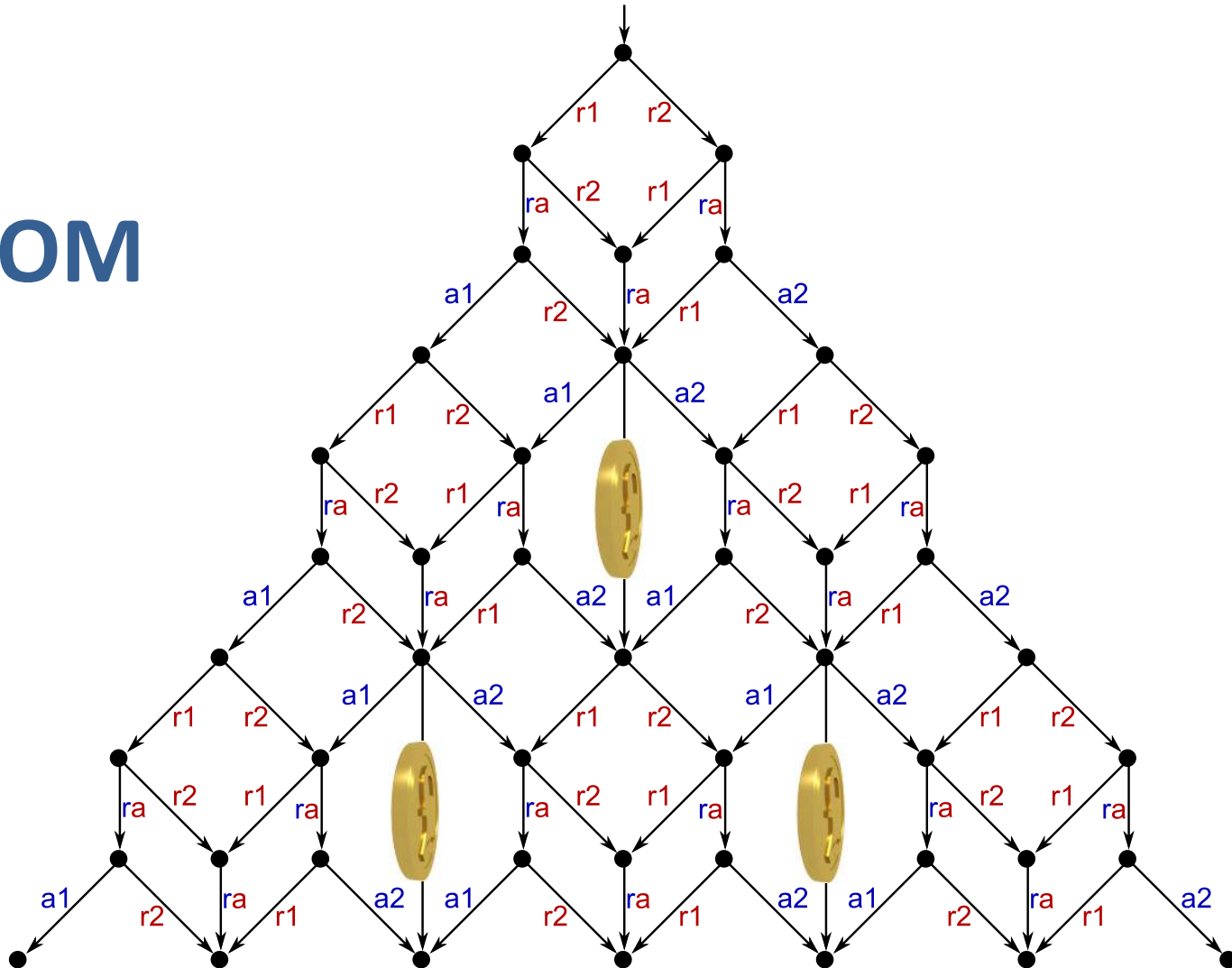
Conceptual specification (unrolled)

Merge

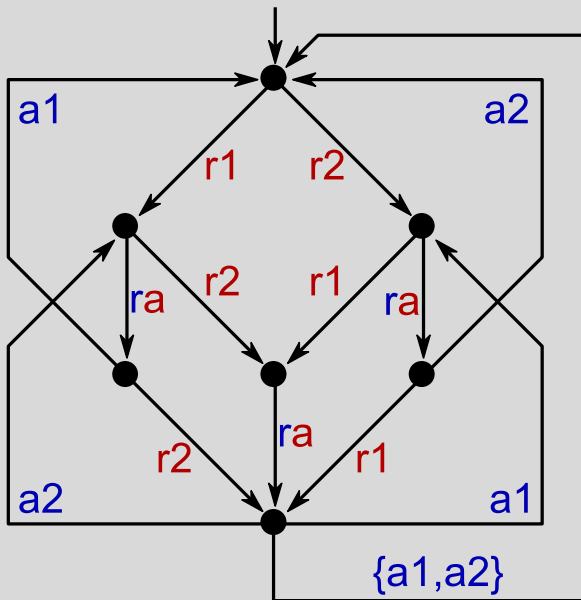


Conceptual specification (unrolled)

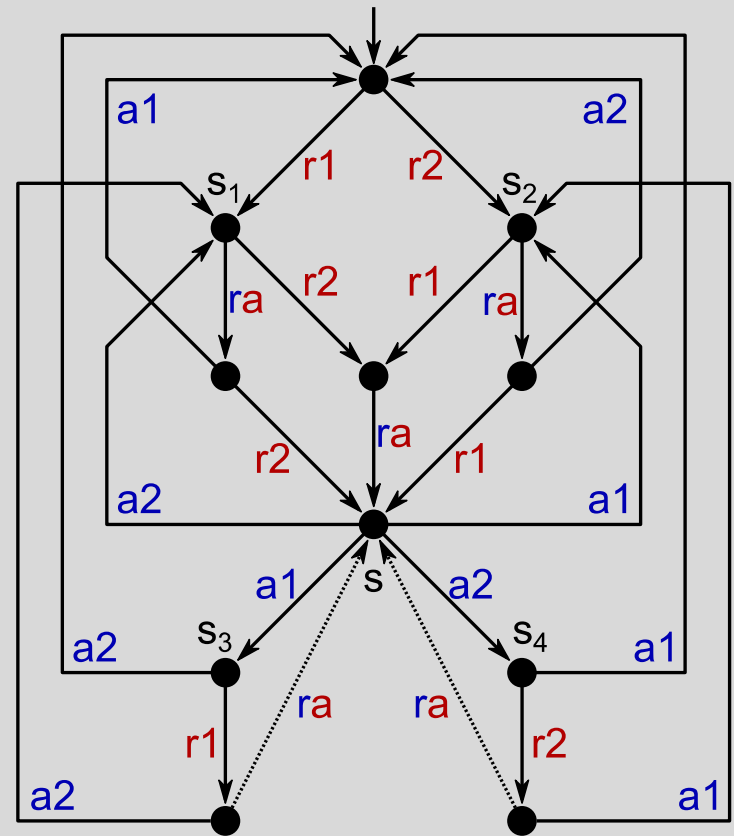
OM



Decomposing the bundle



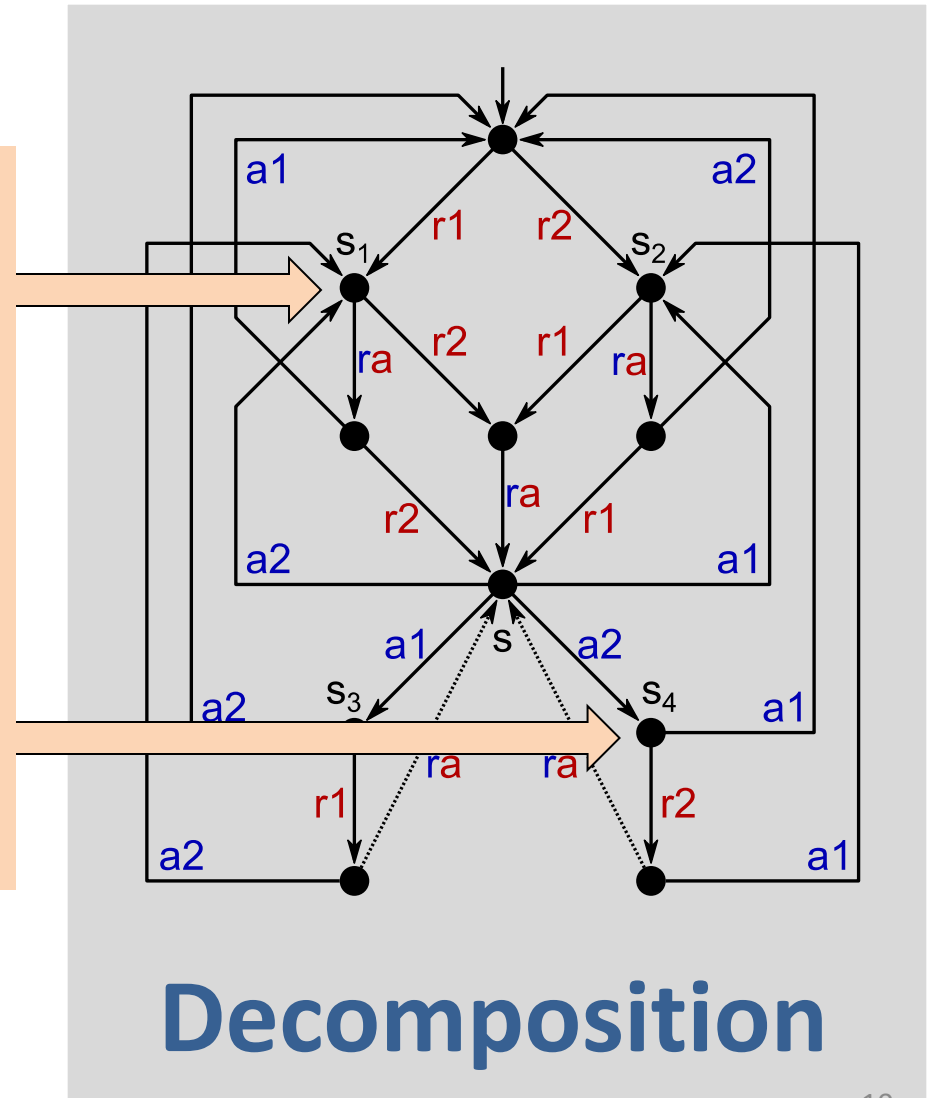
OM with bundle



Decomposition

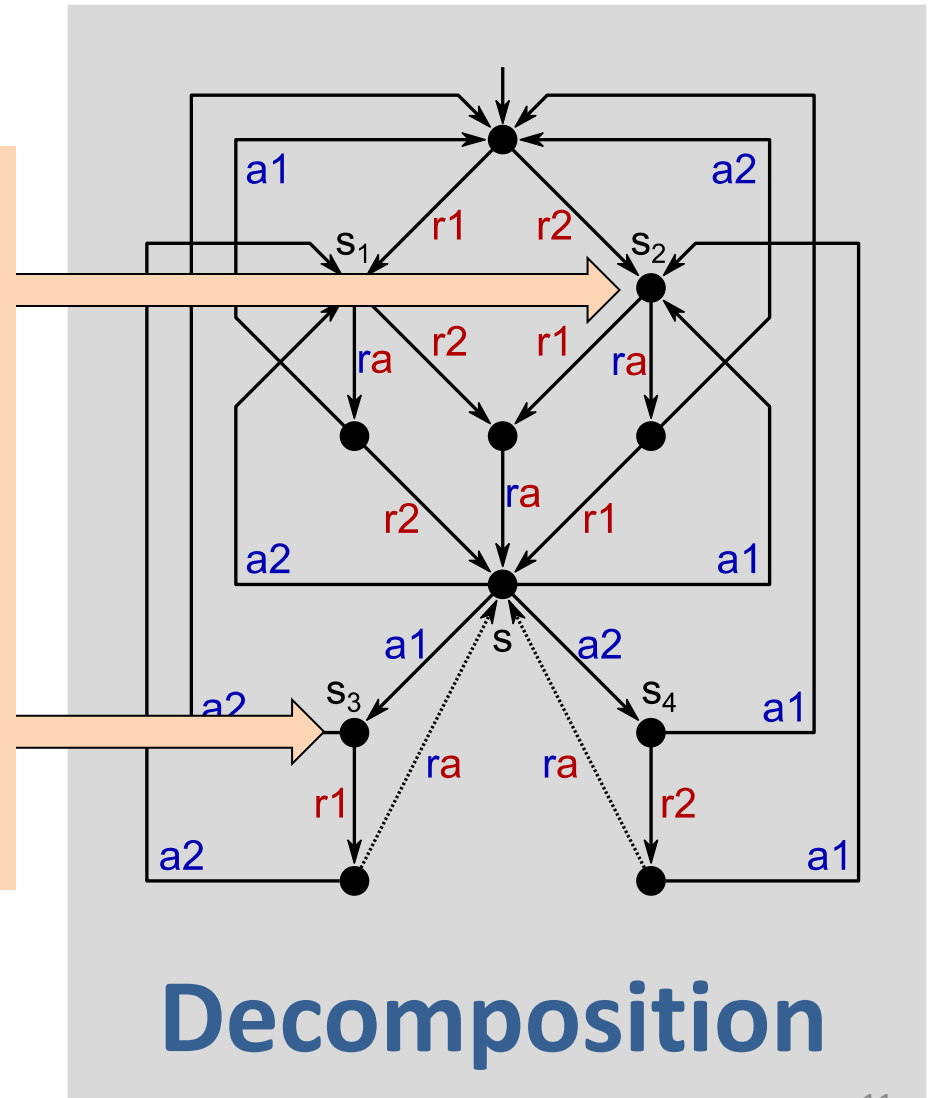
Decomposing the bundle

Problem: decomposed specification cannot be synthesised due to *irreducible state encoding (CSC) conflicts* between s_1 and s_4 , and between s_2 and s_3



Decomposing the bundle

Problem: decomposed specification cannot be synthesised due to *irreducible state encoding (CSC) conflicts* between s_1 and s_4 , and between s_2 and s_3



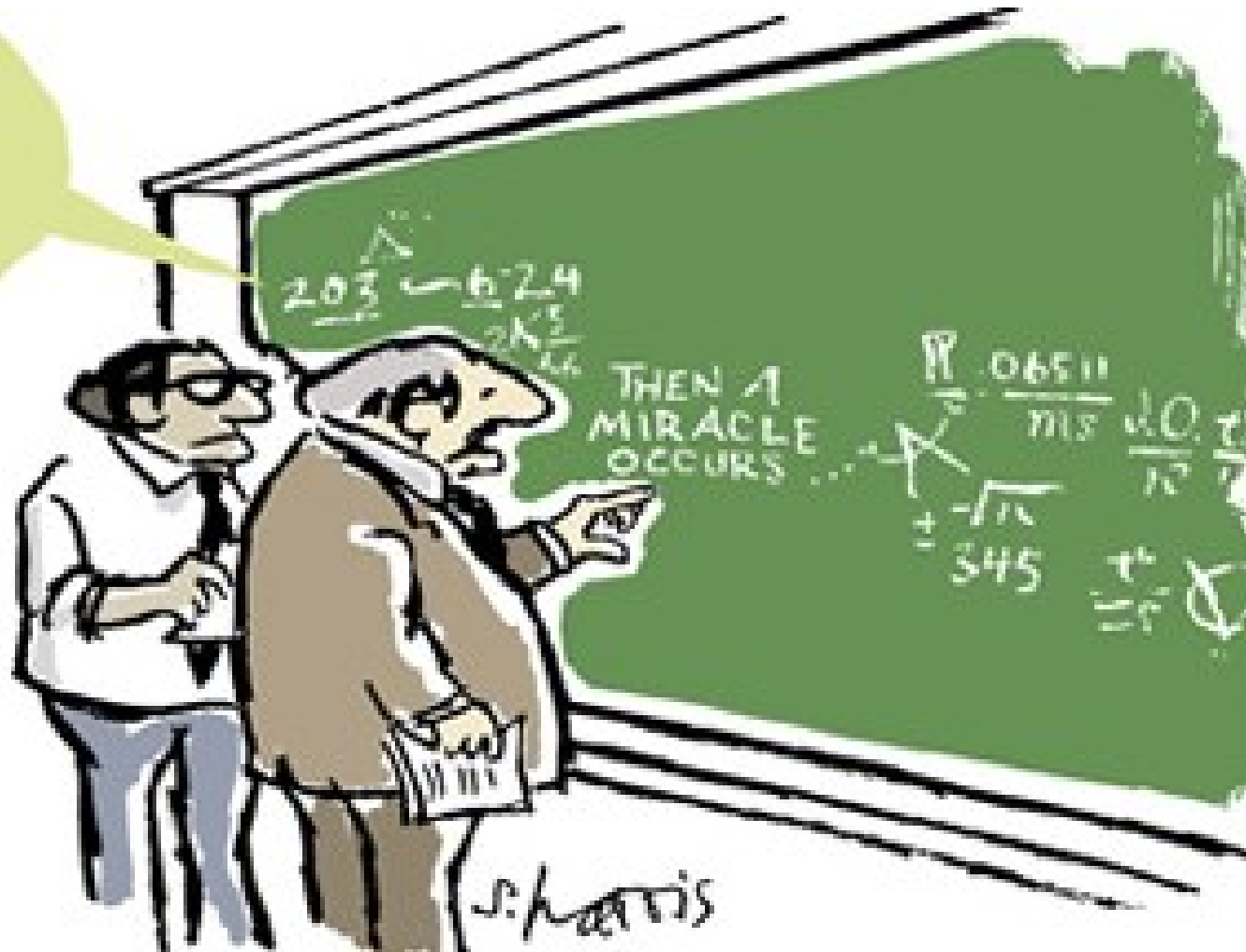
Is this a dead end?

Decomposing the bundle $\{a1, a2\}$ is highly non-trivial:

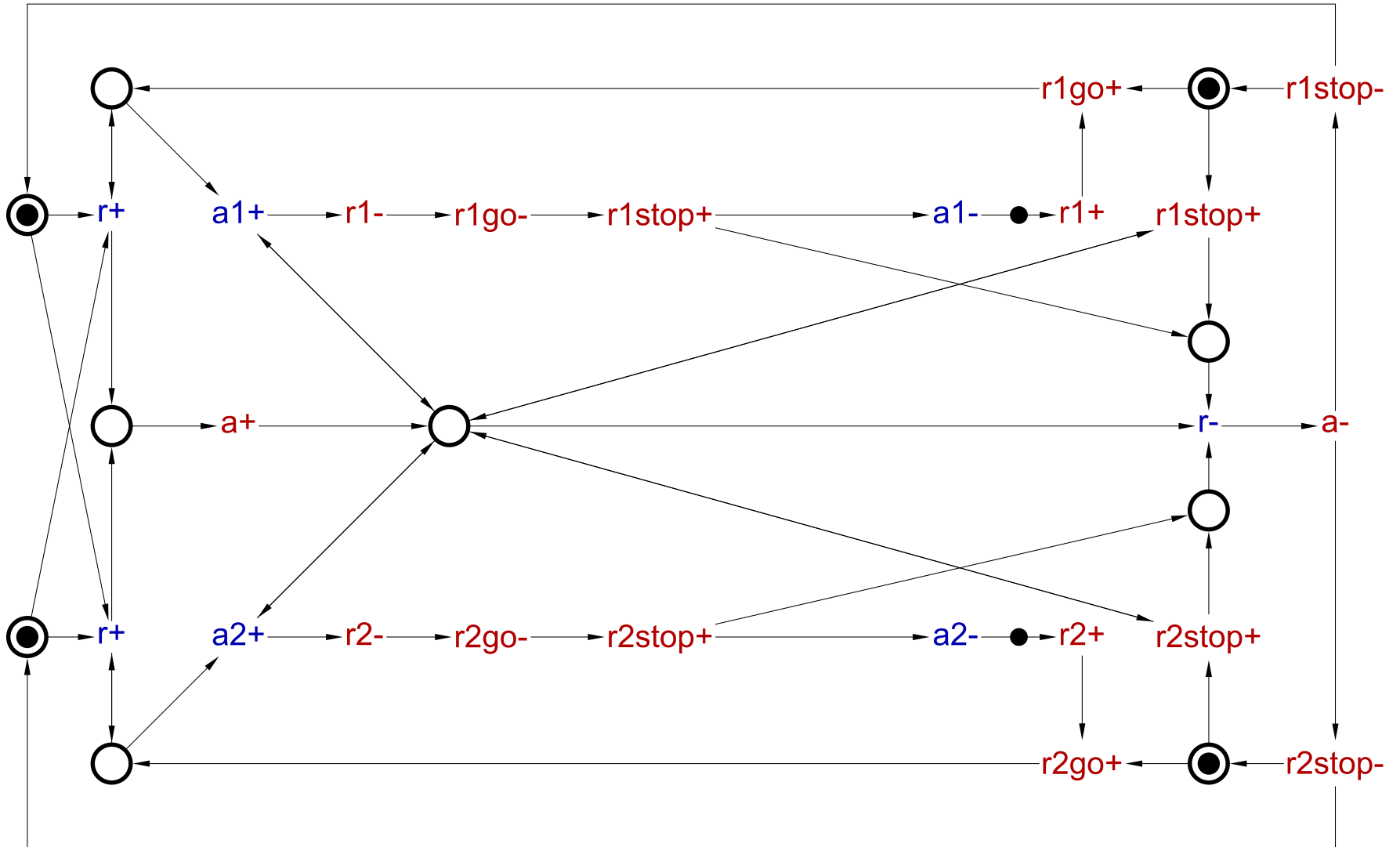
- Output-determinacy violations
- Non-commutativity of inputs
- Irreducible CSC conflicts
- ...

...then a miracle occurs...

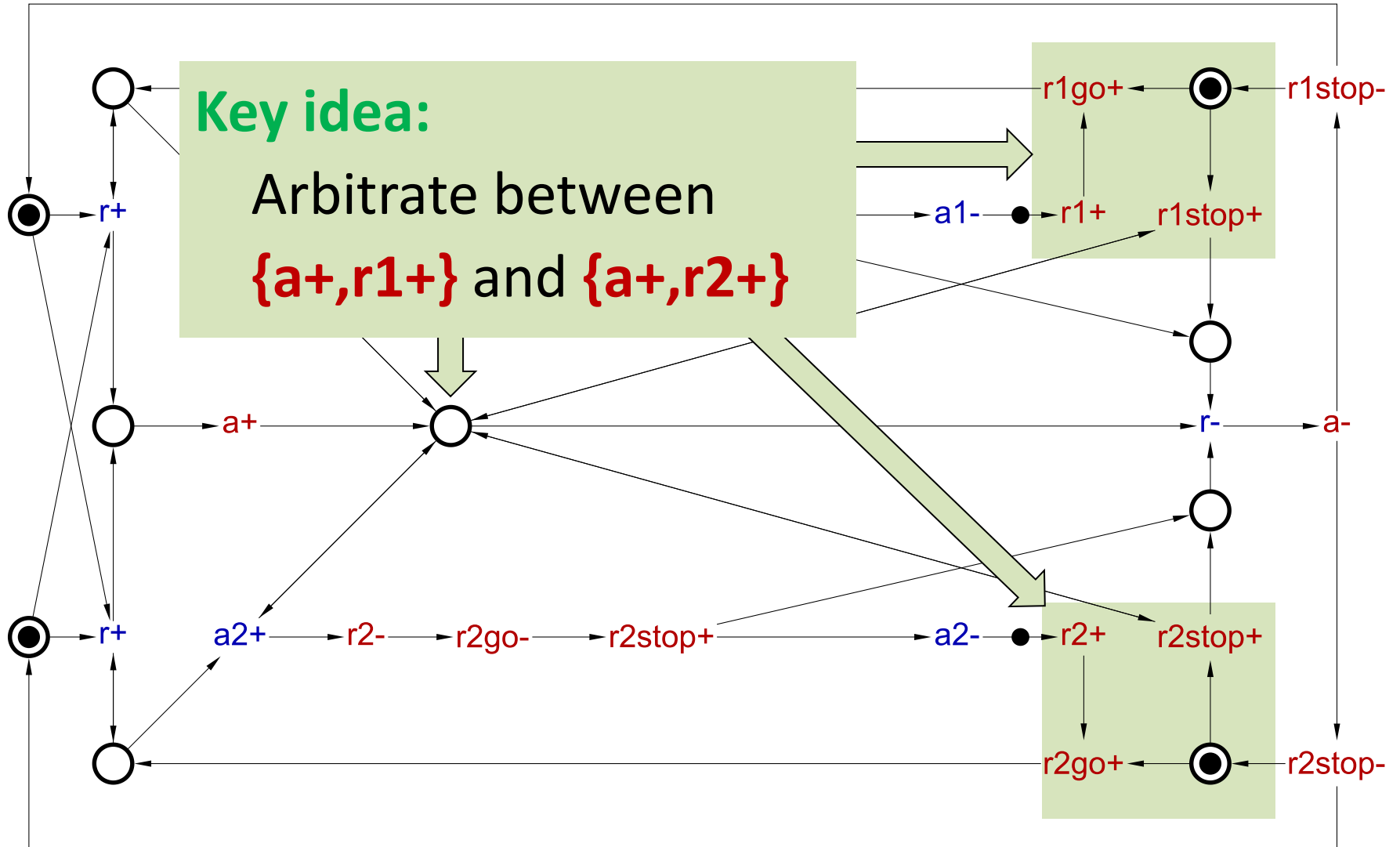
I THINK YOU SHOULD BE MORE SPECIFIC HERE IN STEP TWO



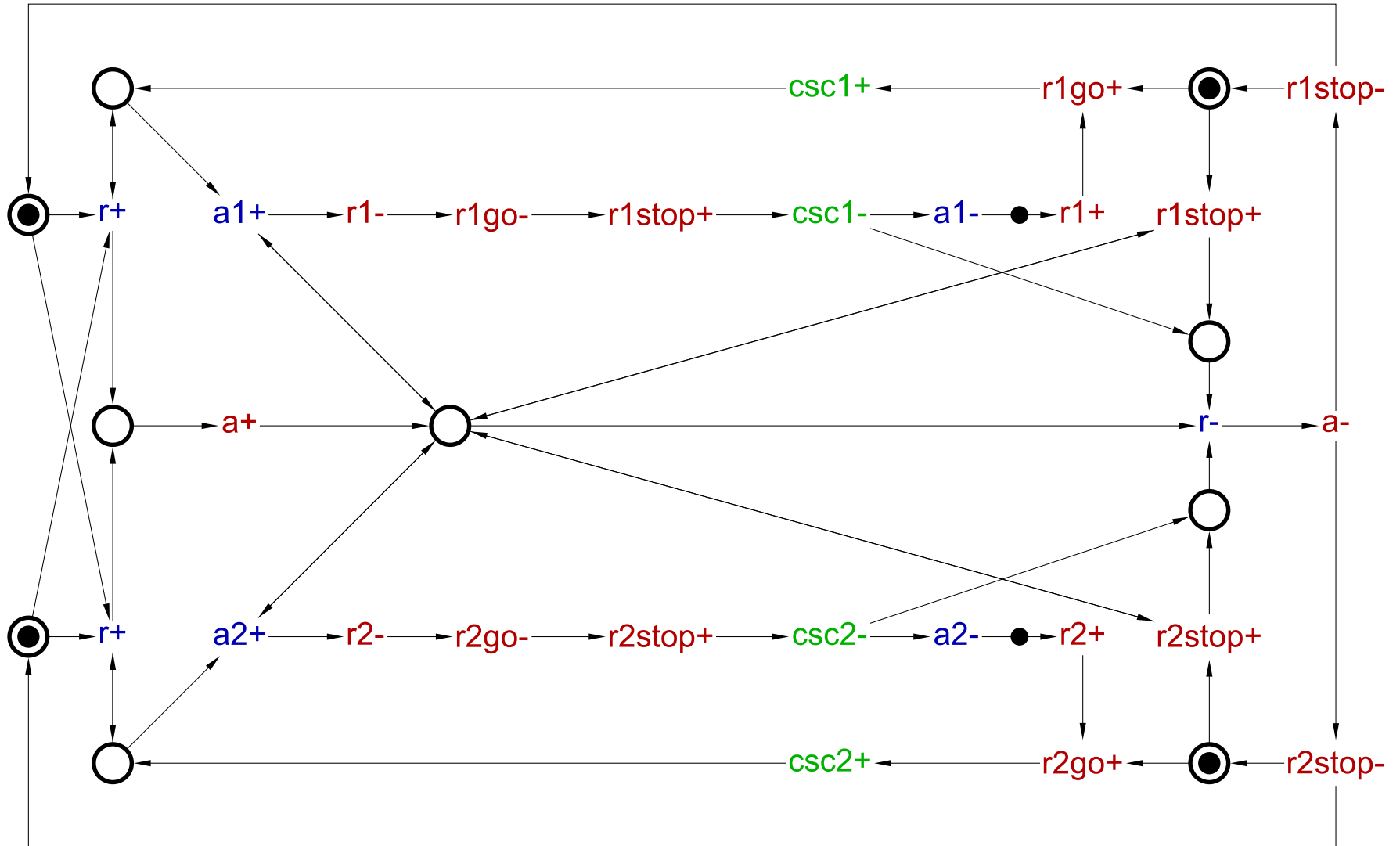
STG specification



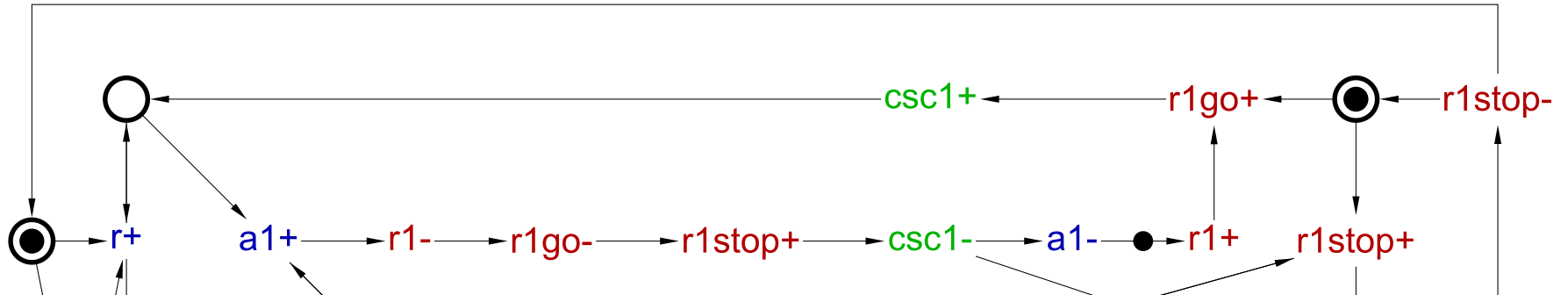
STG specification



CSC resolution (MPSAT)



CSC resolution (MPSAT)

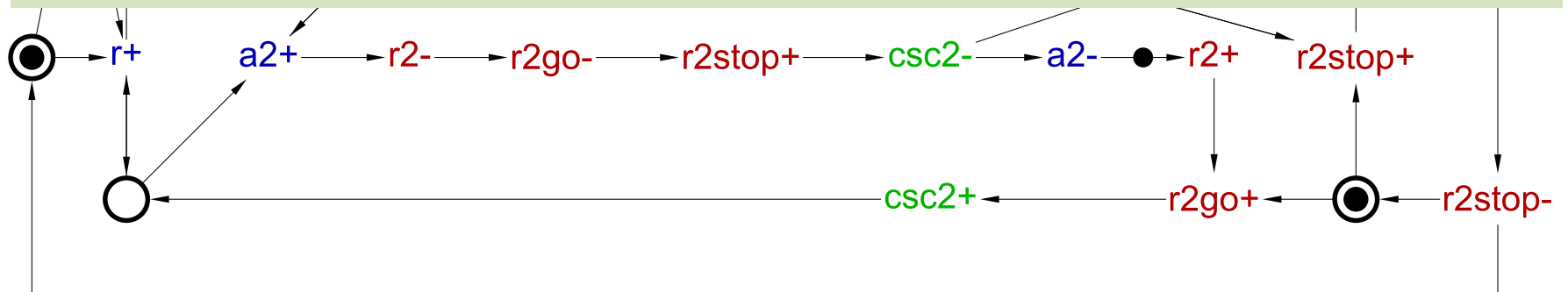


Deadlock free

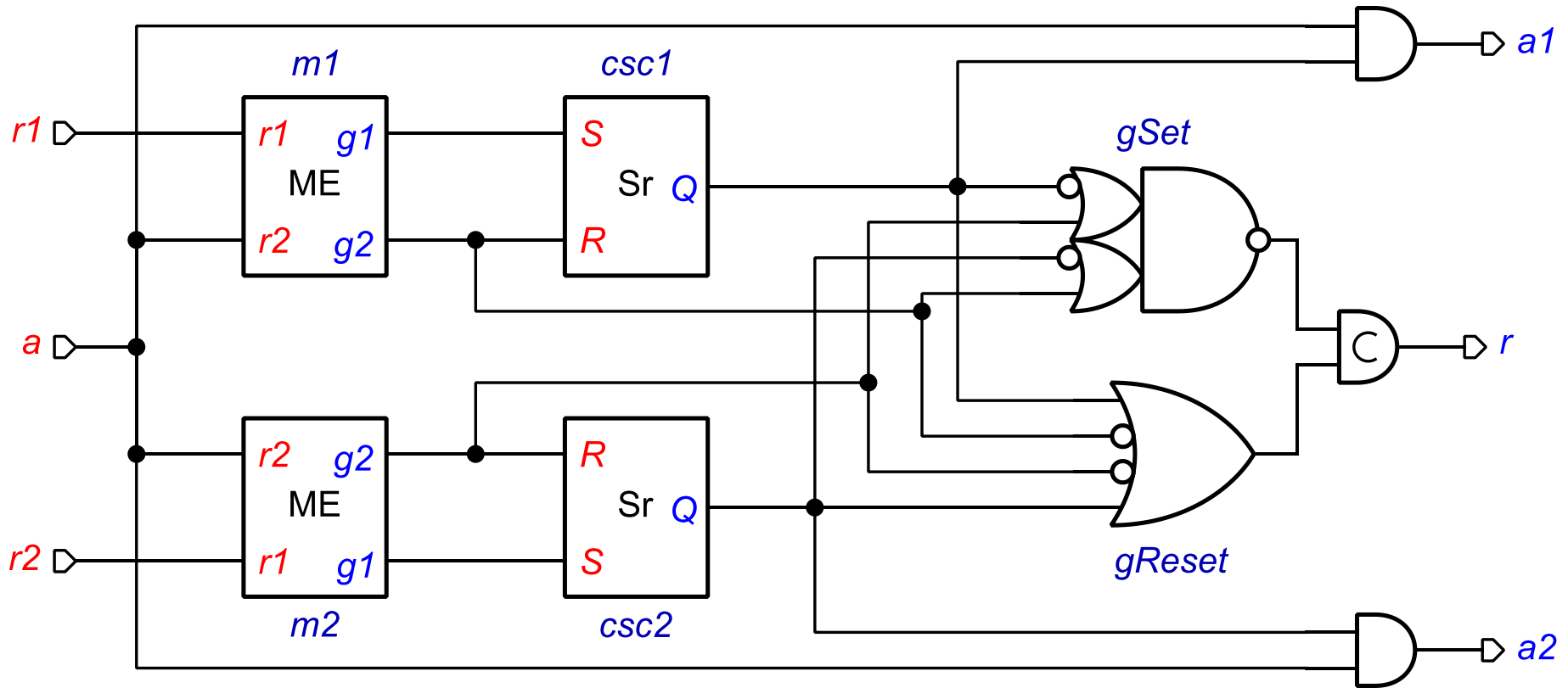
No hazards

Synthesisable

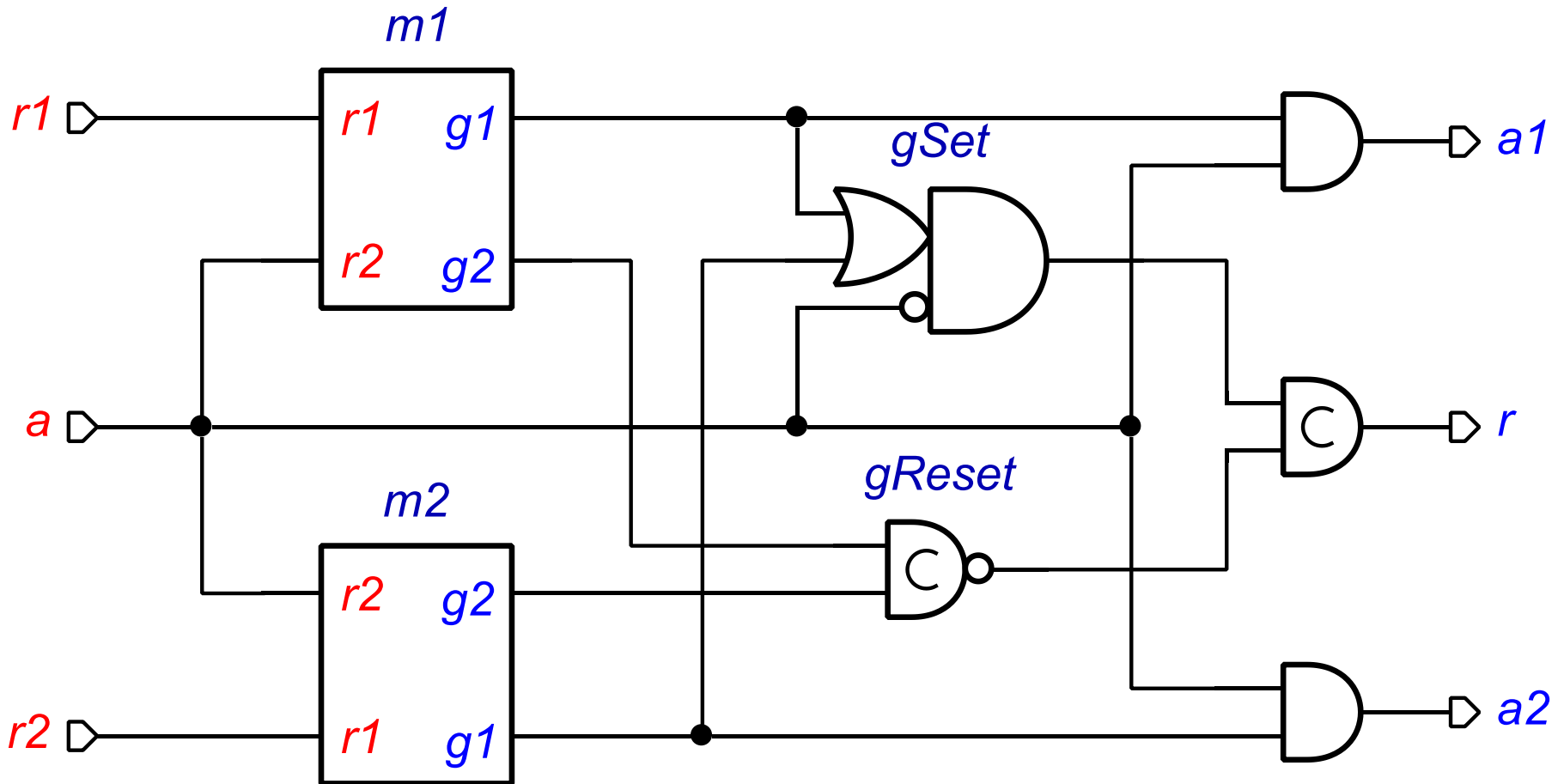
Fast response: no metastability on the critical path



Synthesised circuit (MPSAT)

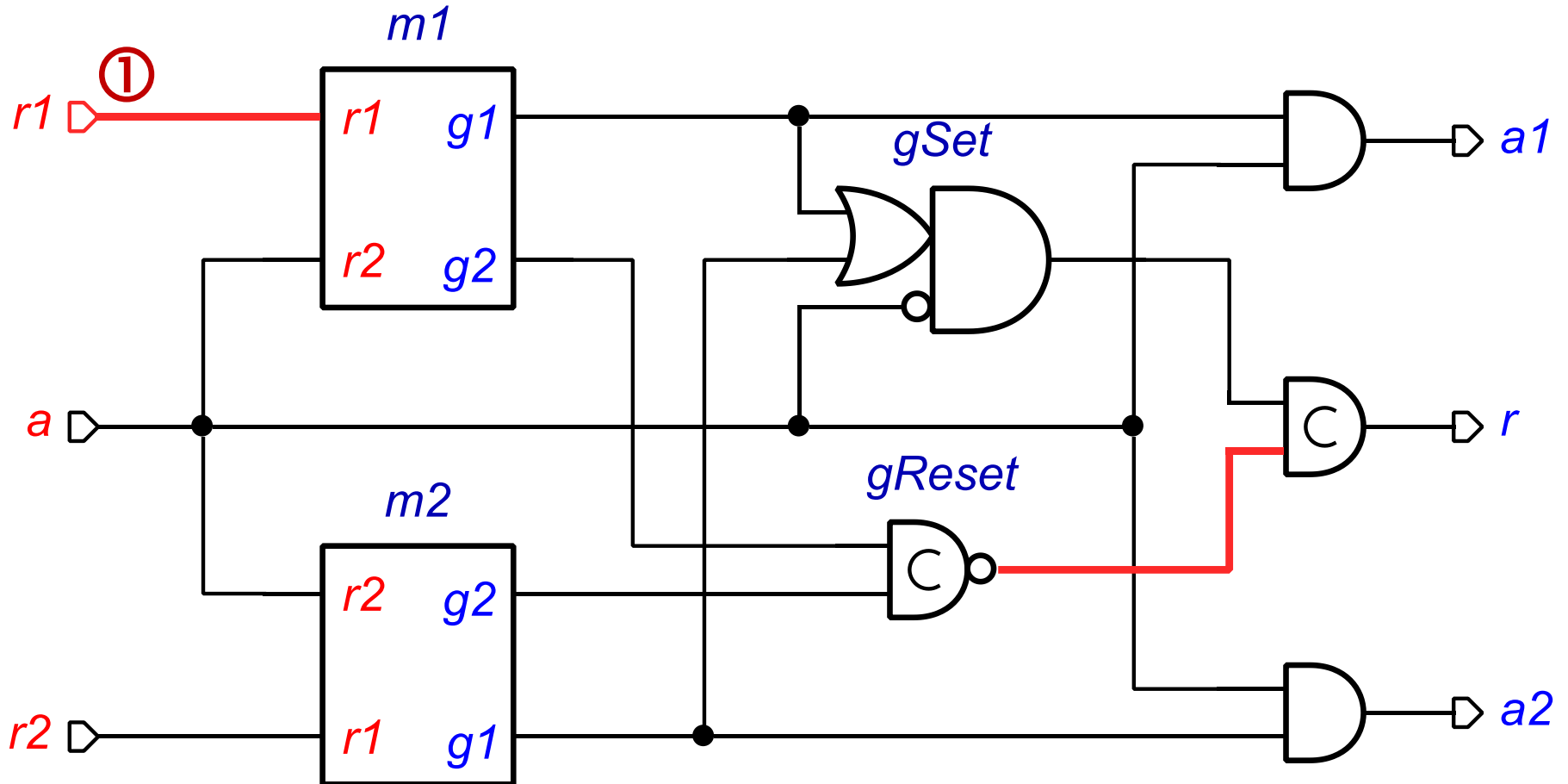


Simplified (hacked up) circuit

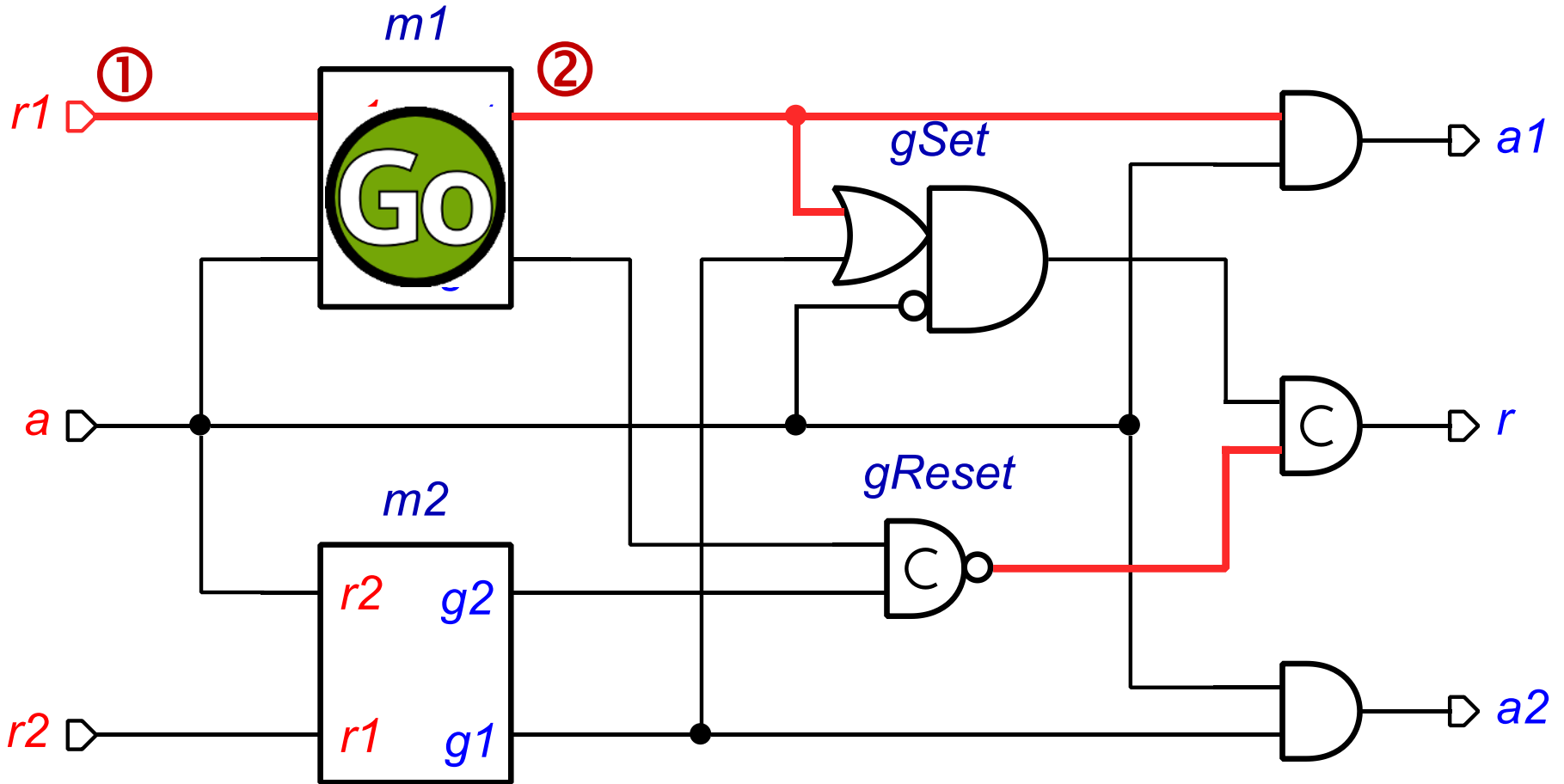


New optimisation technique: **fairness-based optimisation**

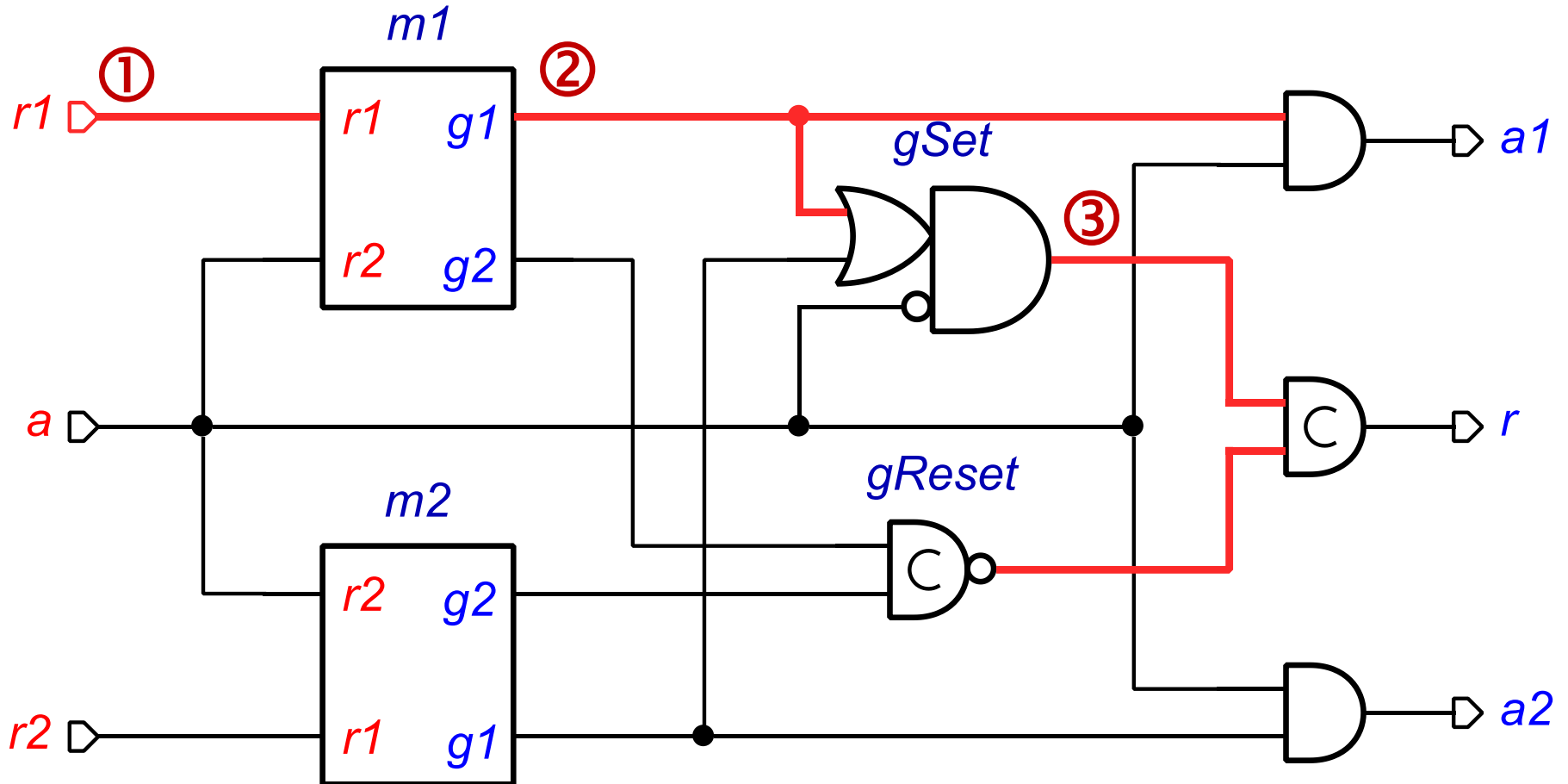
Simplified (hacked up) circuit



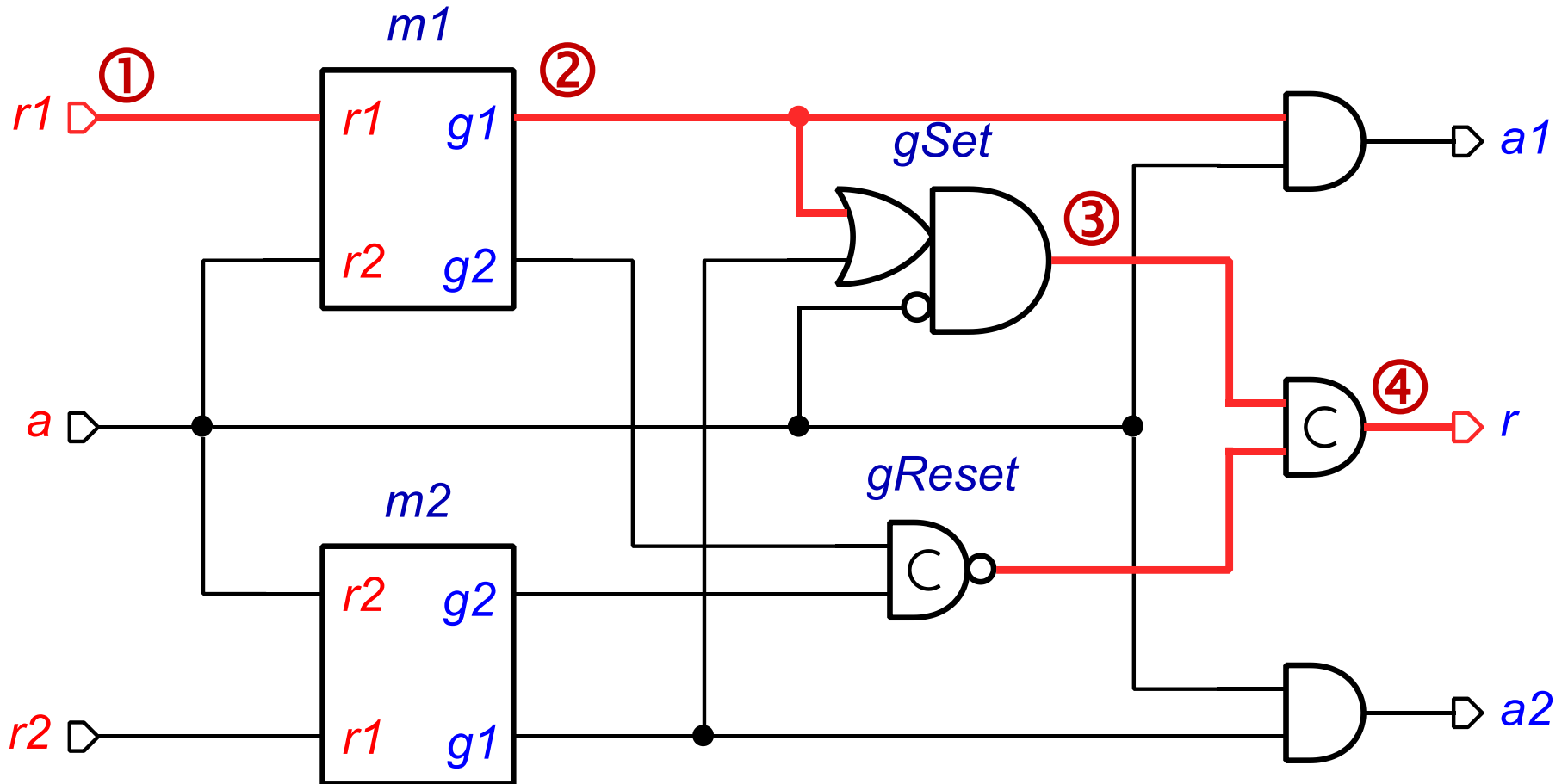
Simplified (hacked up) circuit



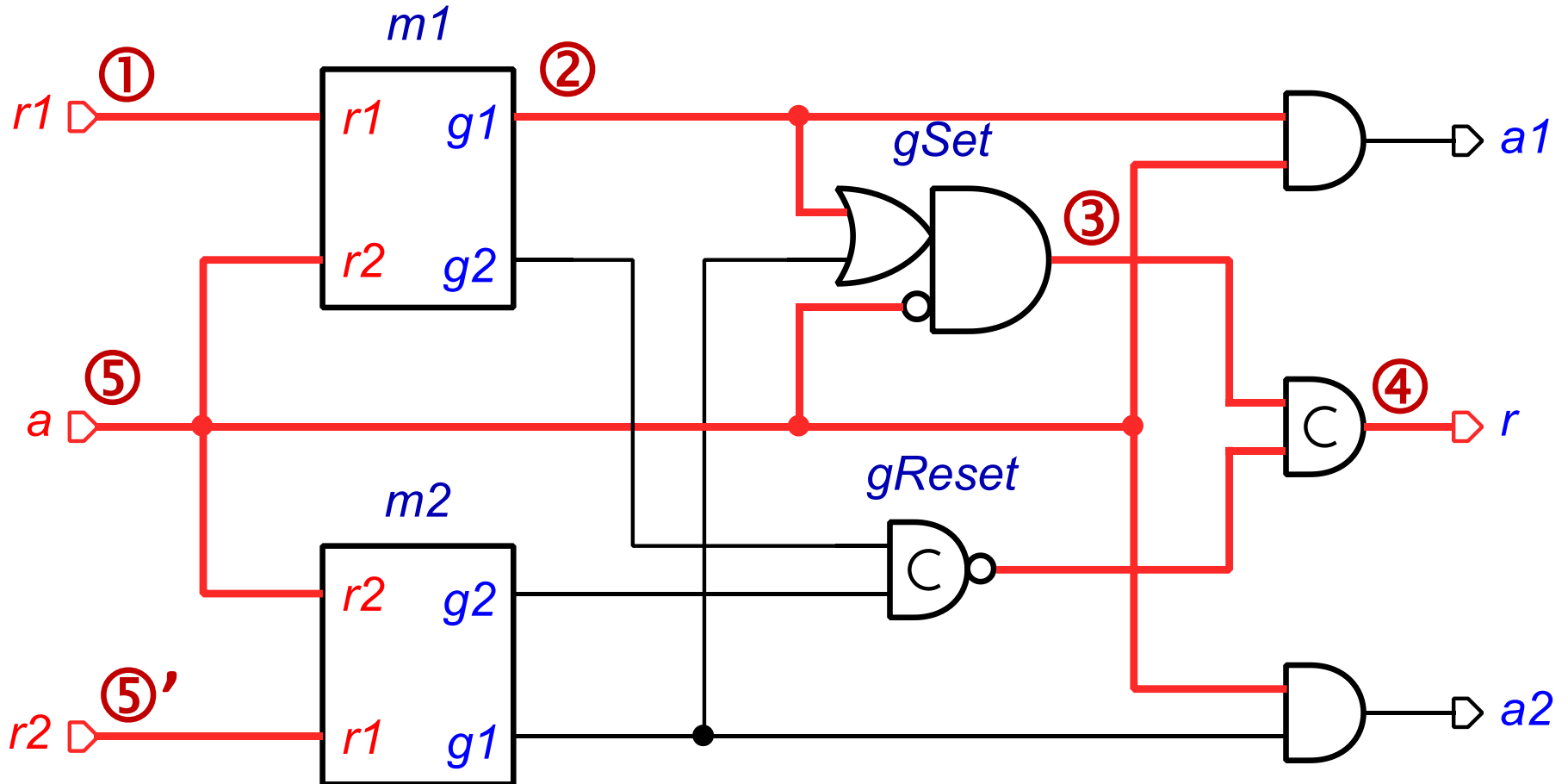
Simplified (hacked up) circuit



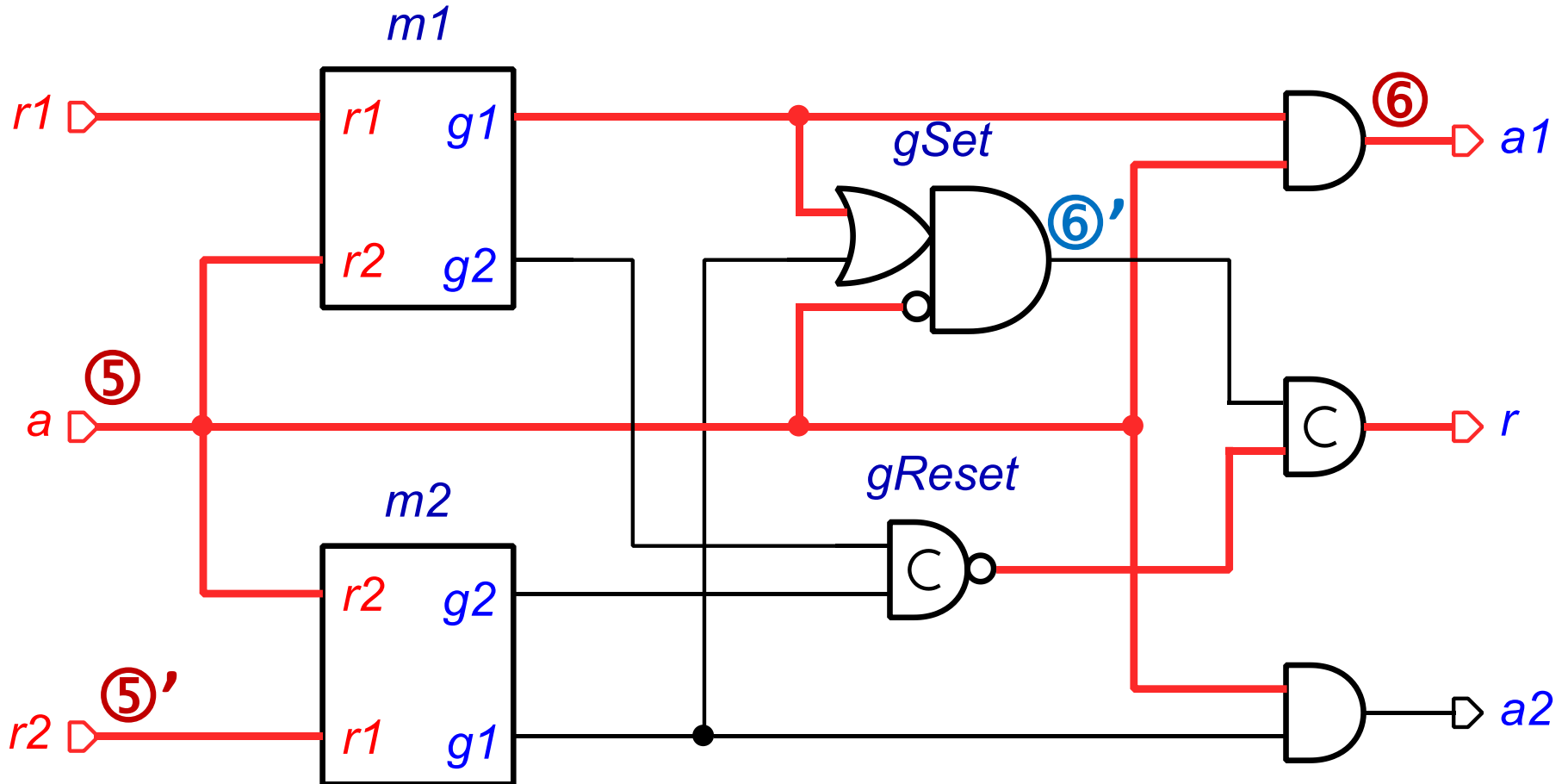
Simplified (hacked up) circuit



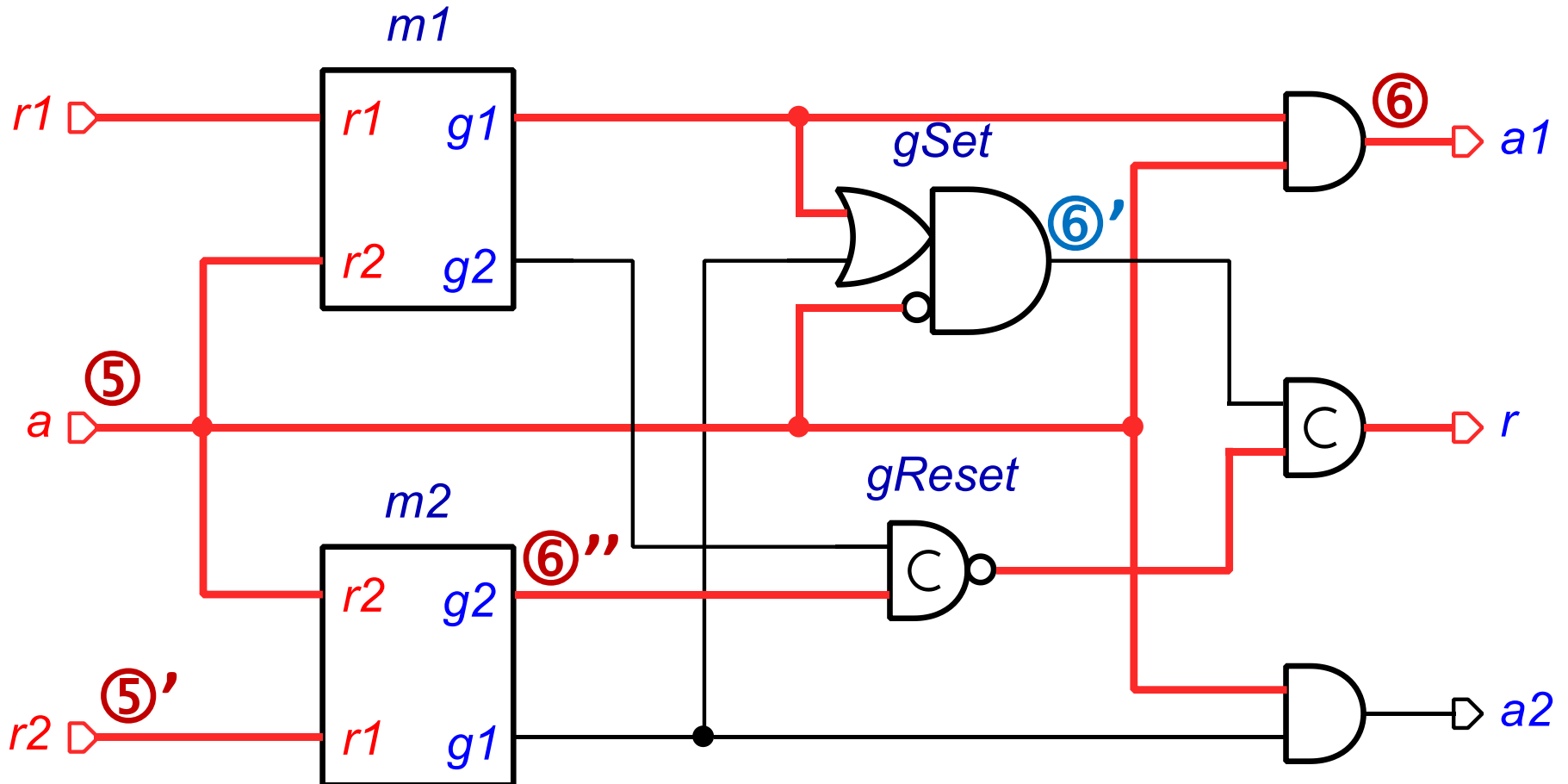
Simplified (hacked up) circuit



Simplified (hacked up) circuit

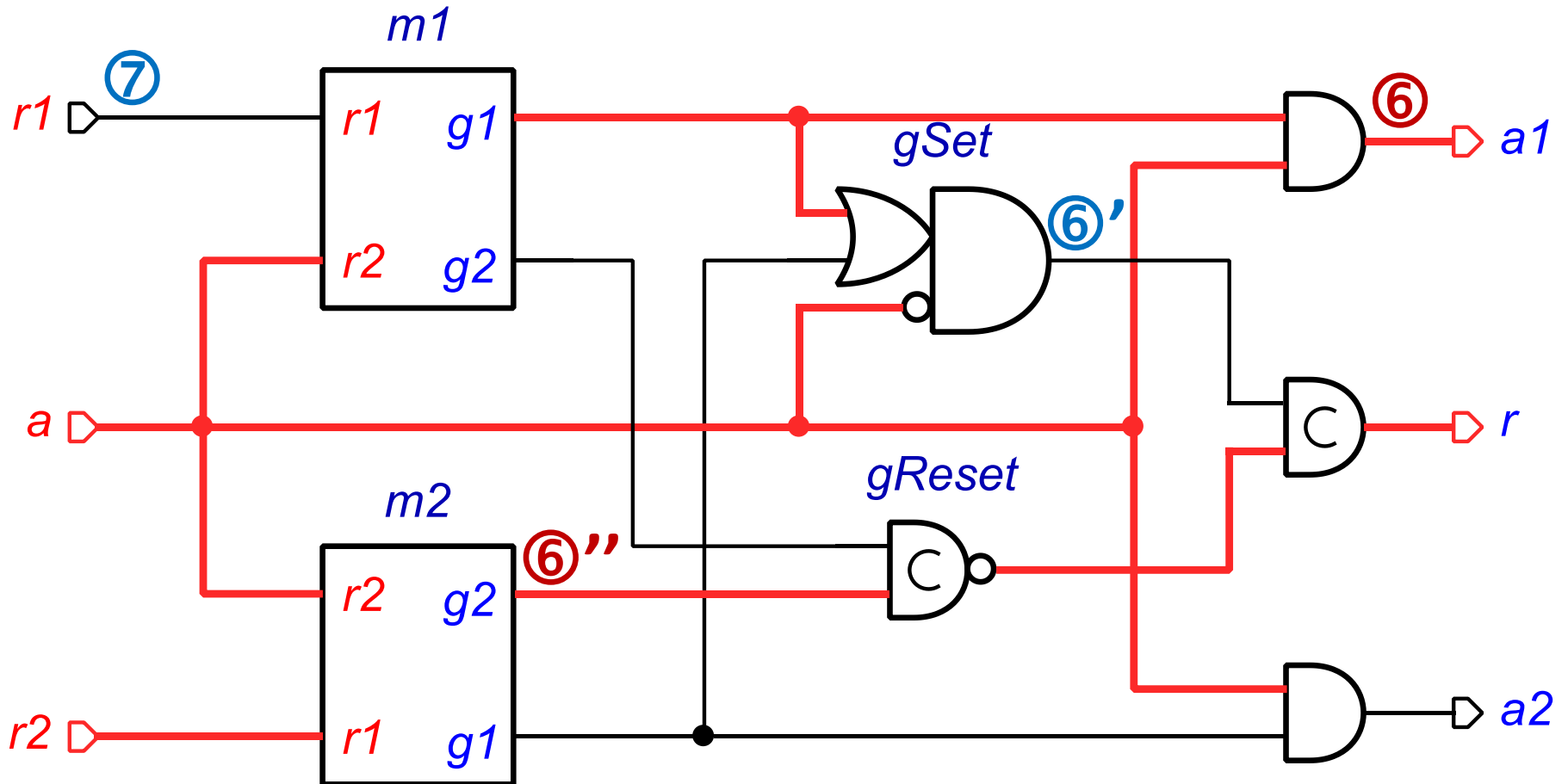


Simplified (hacked up) circuit



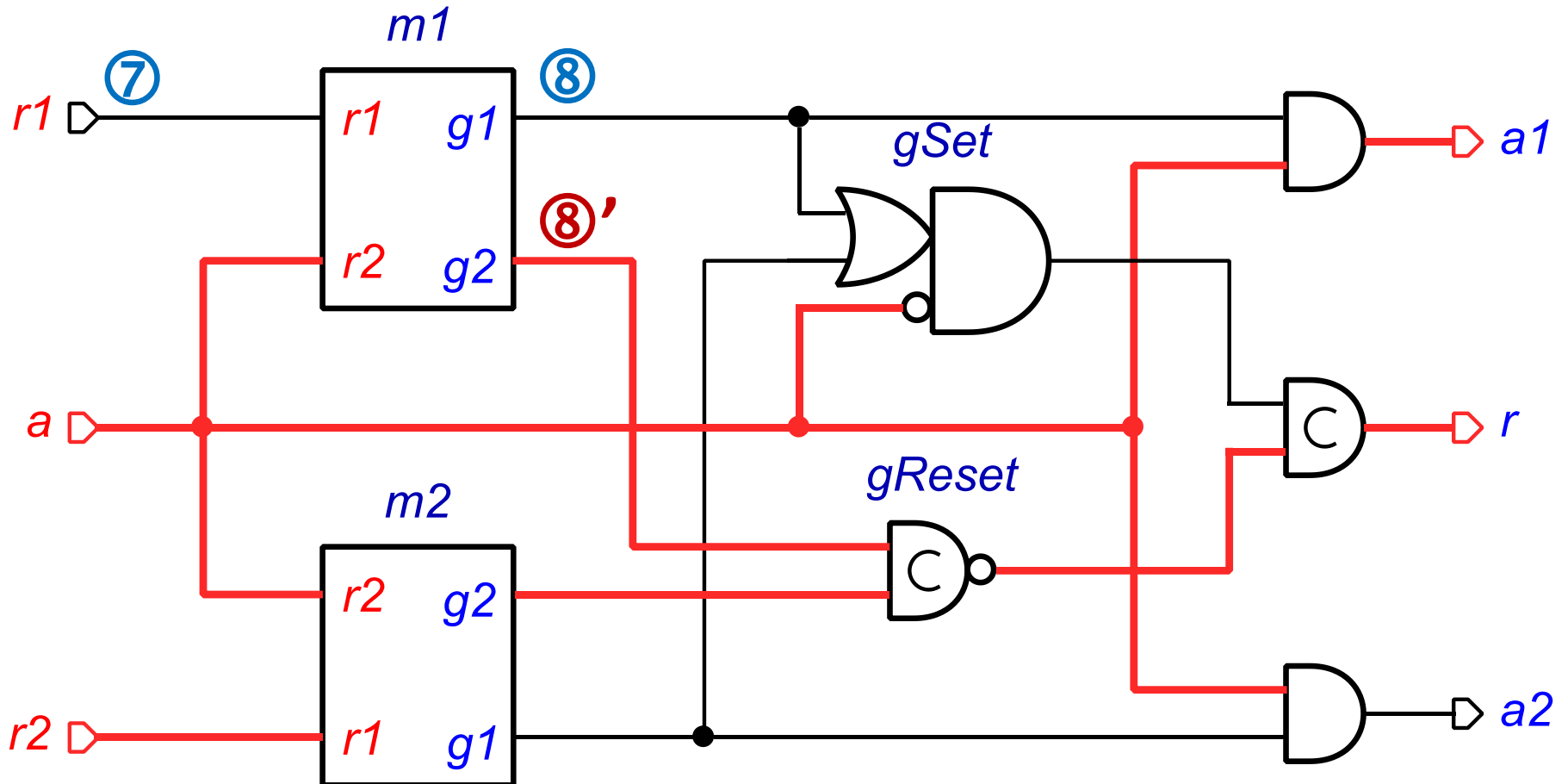
Scenario 1: acknowledgement **a** wins the arbitration

Simplified (hacked up) circuit



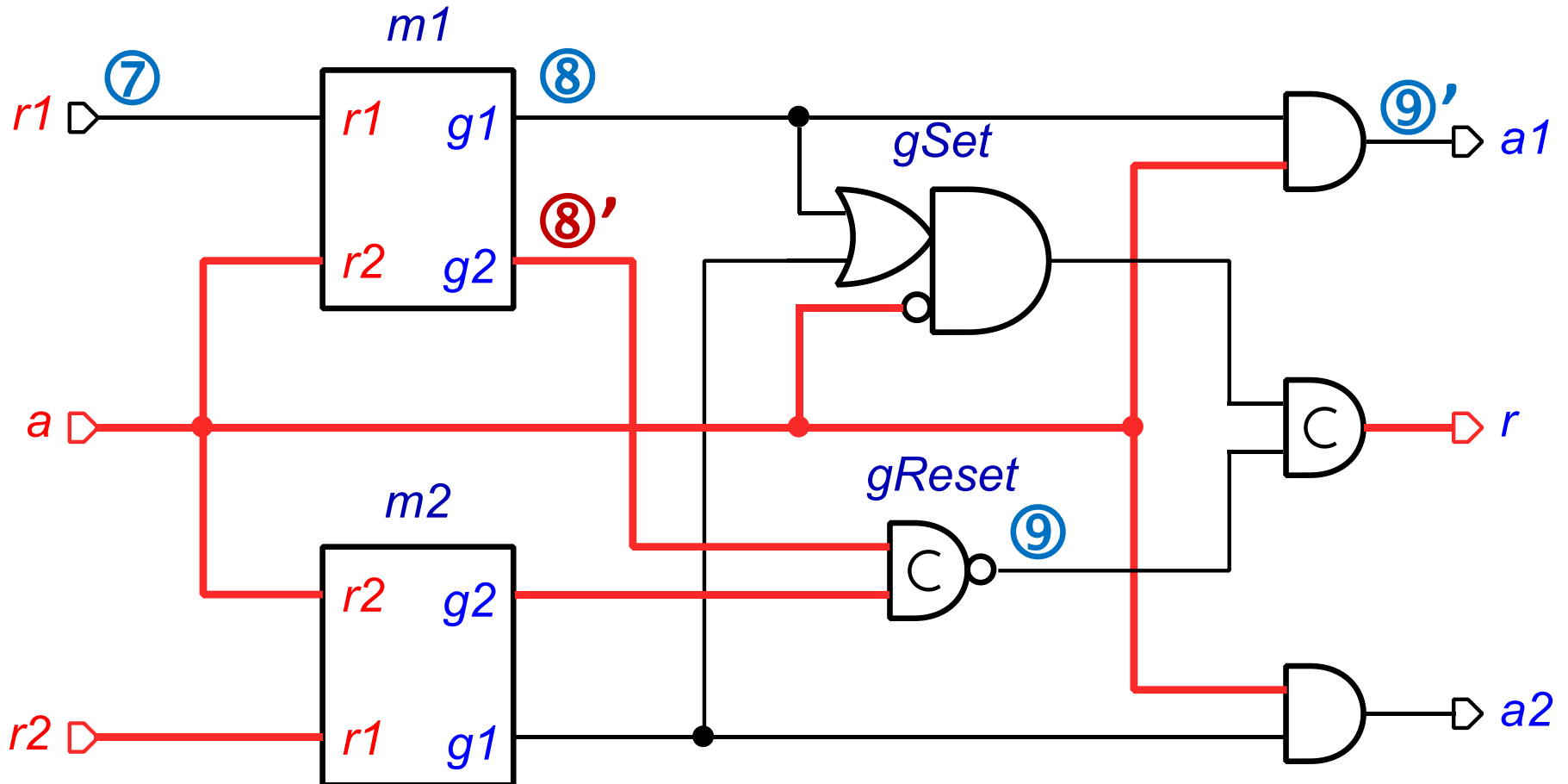
Scenario 1: acknowledgement **a** wins the arbitration

Simplified (hacked up) circuit



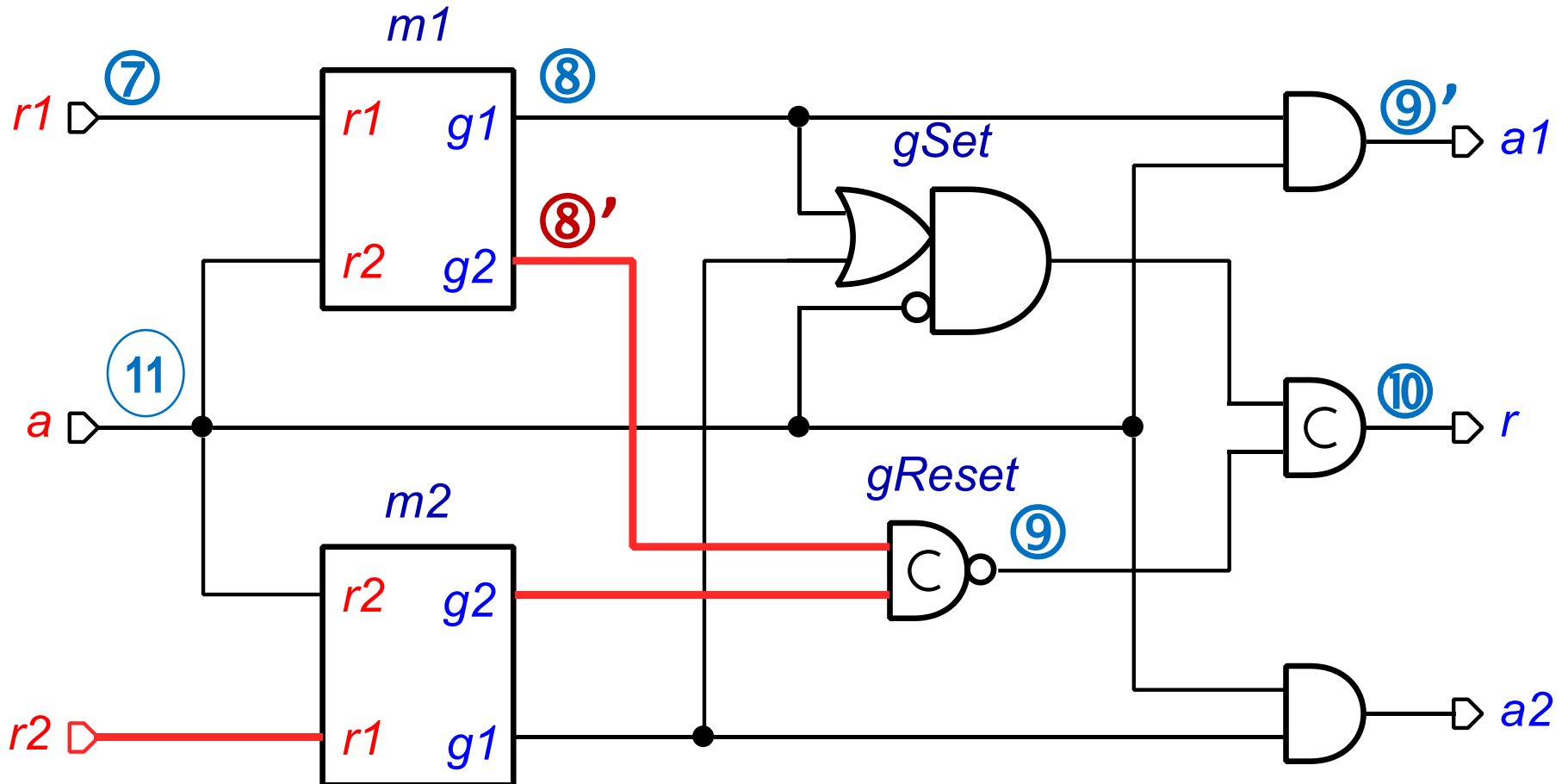
Scenario 1: acknowledgement **a** wins the arbitration

Simplified (hacked up) circuit



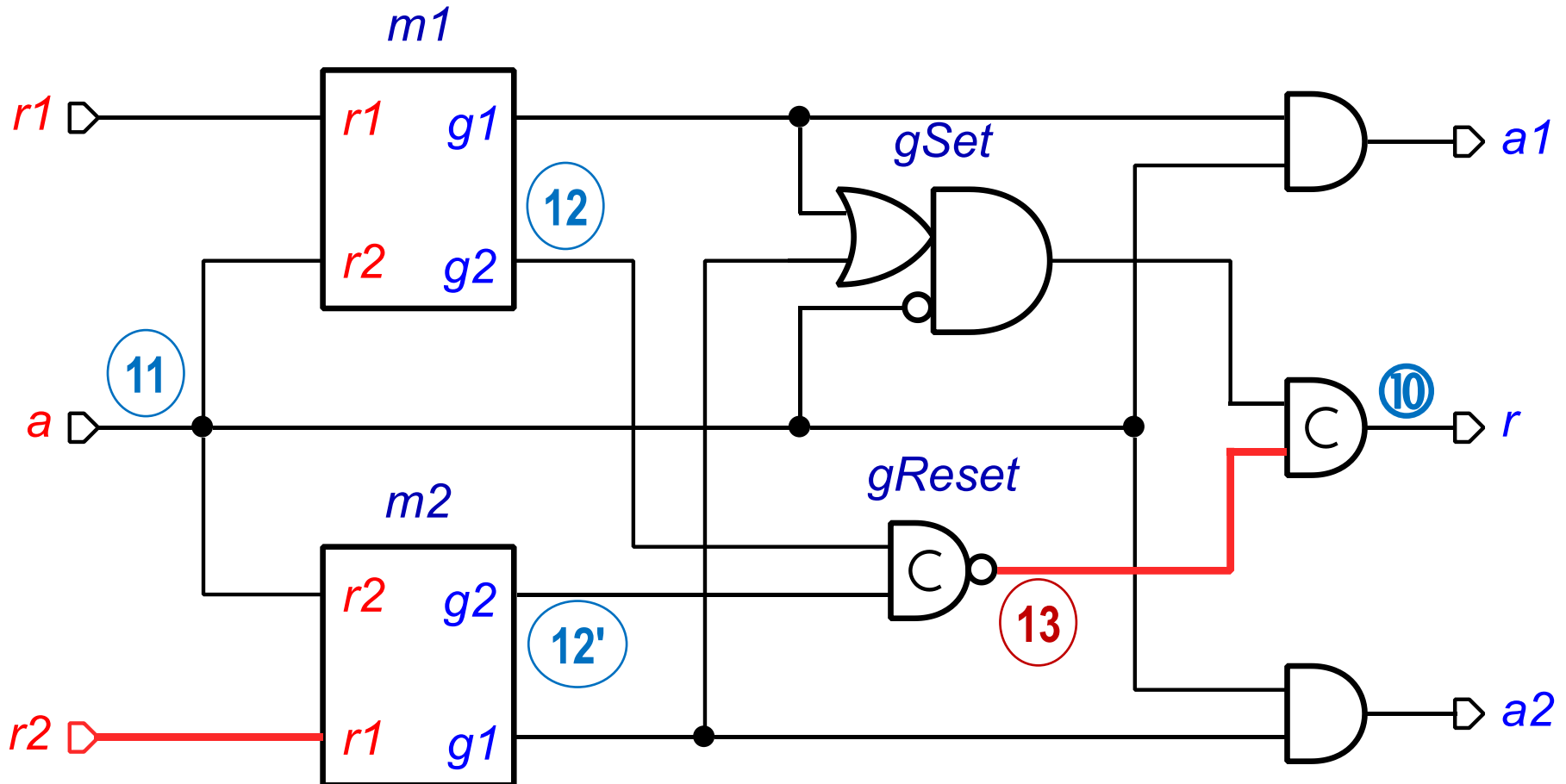
Scenario 1: acknowledgement **a** wins the arbitration

Simplified (hacked up) circuit



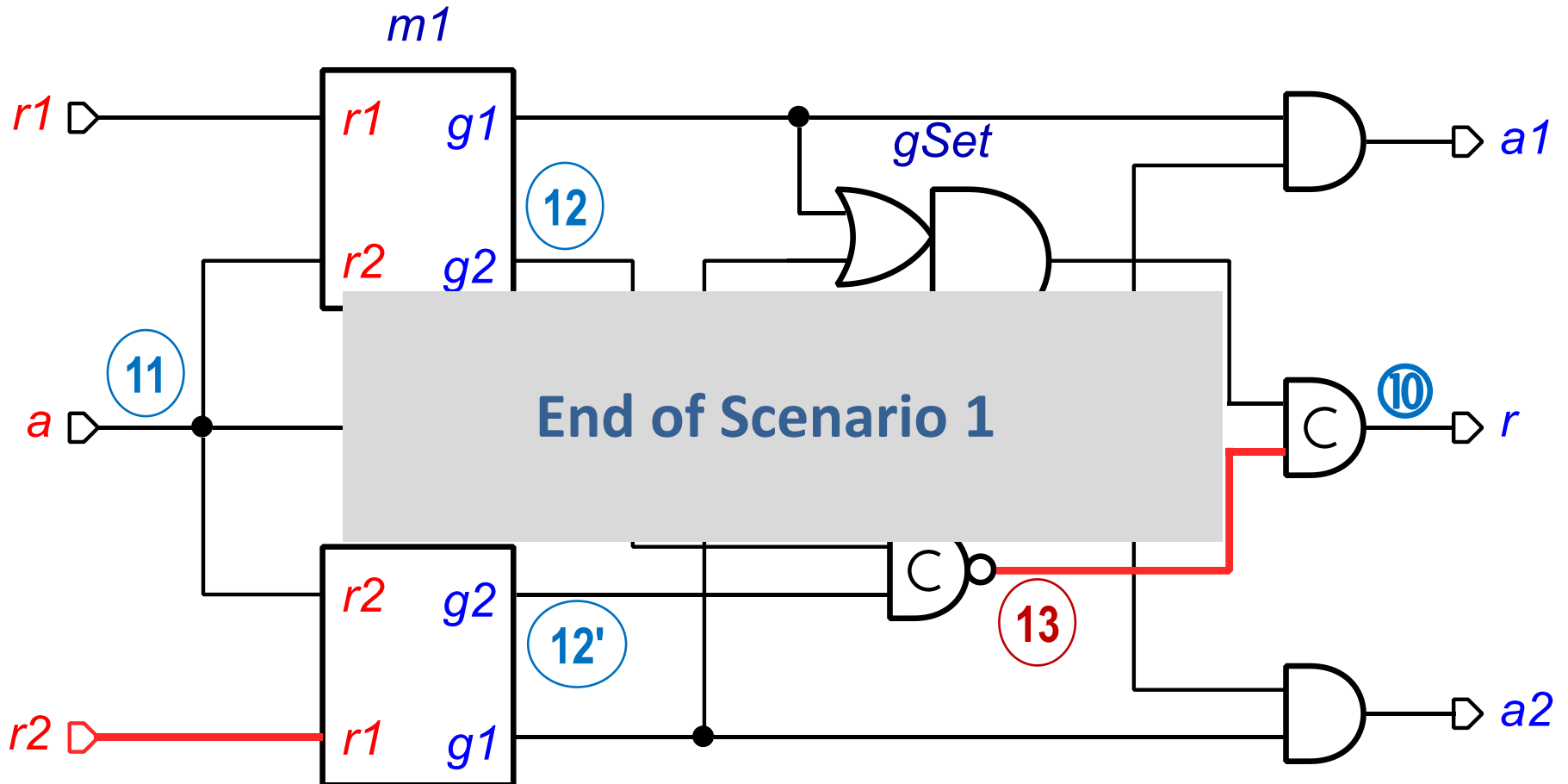
Scenario 1: acknowledgement **a** wins the arbitration

Simplified (hacked up) circuit



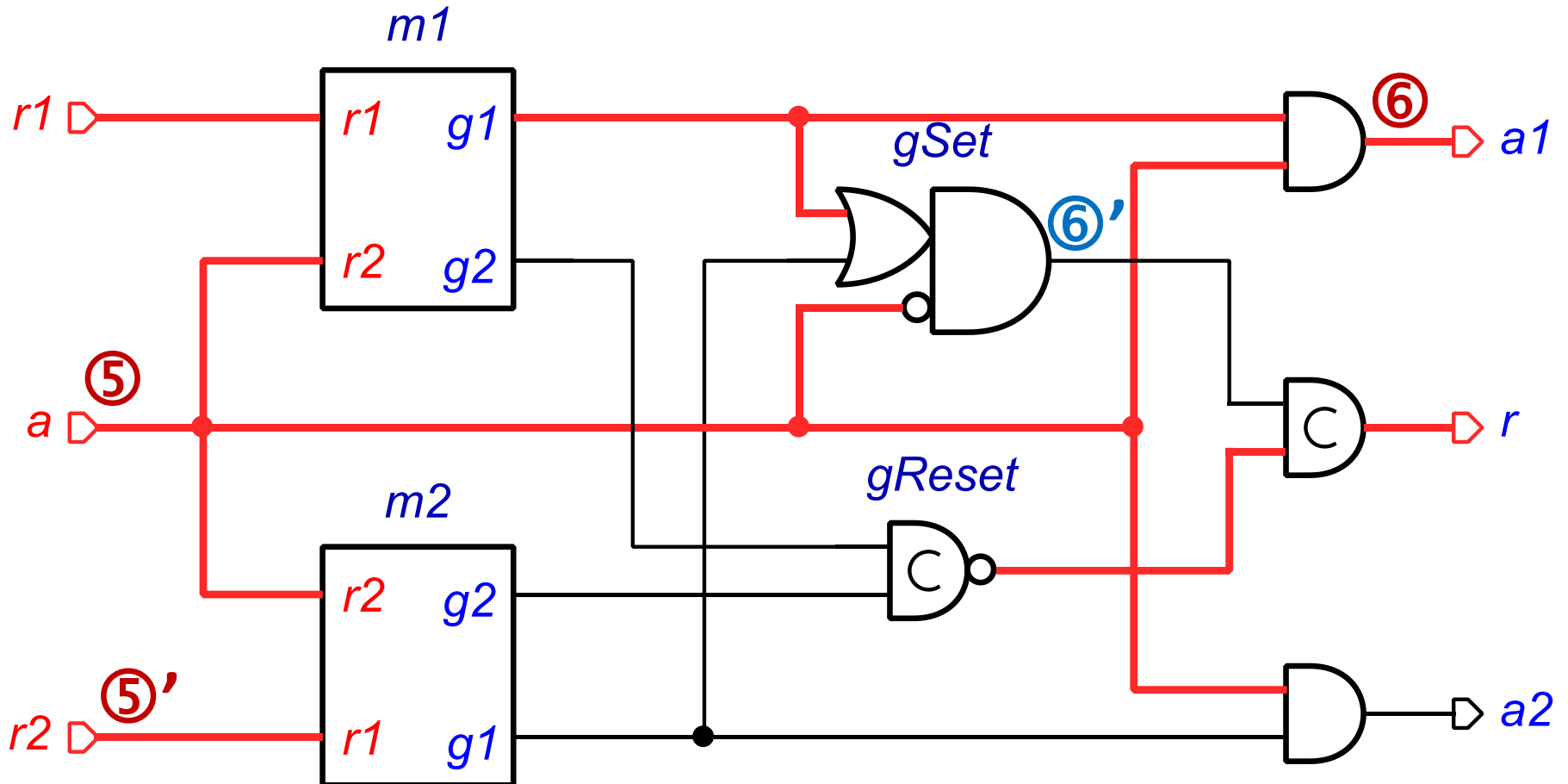
Scenario 1: acknowledgement **a** wins the arbitration

Simplified (hacked up) circuit



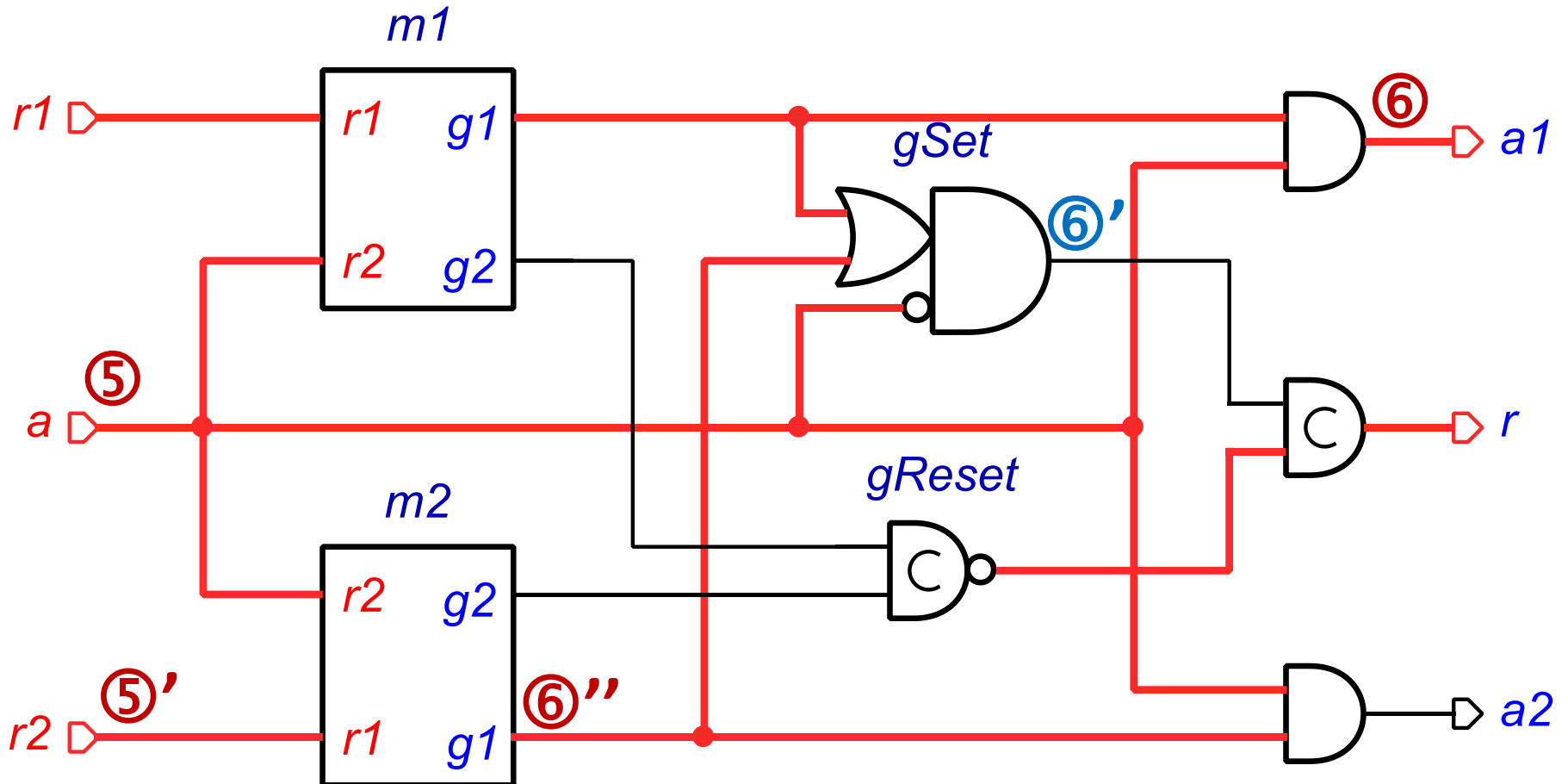
Scenario 1: acknowledgement **a** wins the arbitration

Simplified (hacked up) circuit



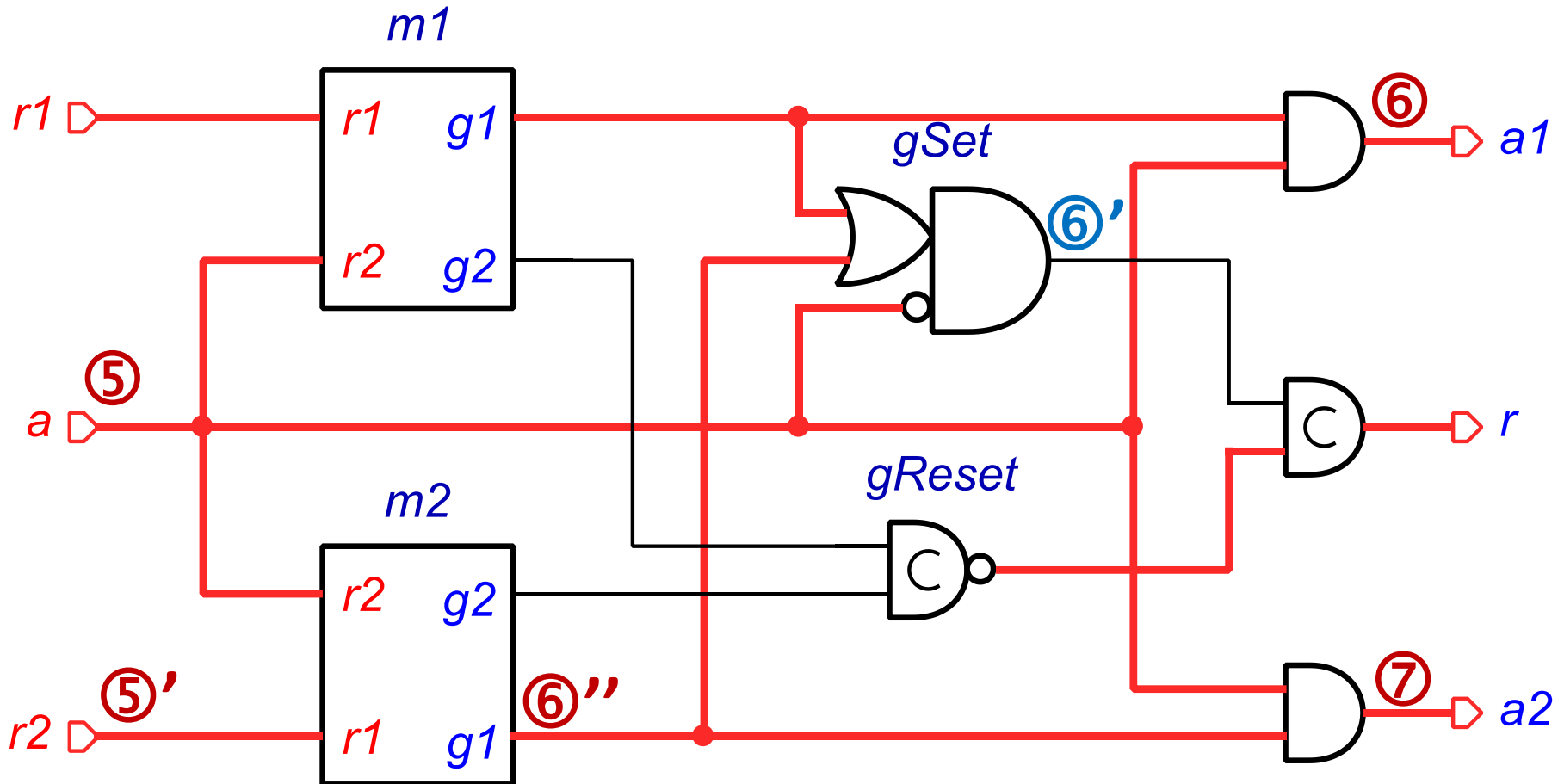
Scenario 2: request $r2$ wins the arbitration

Simplified (hacked up) circuit



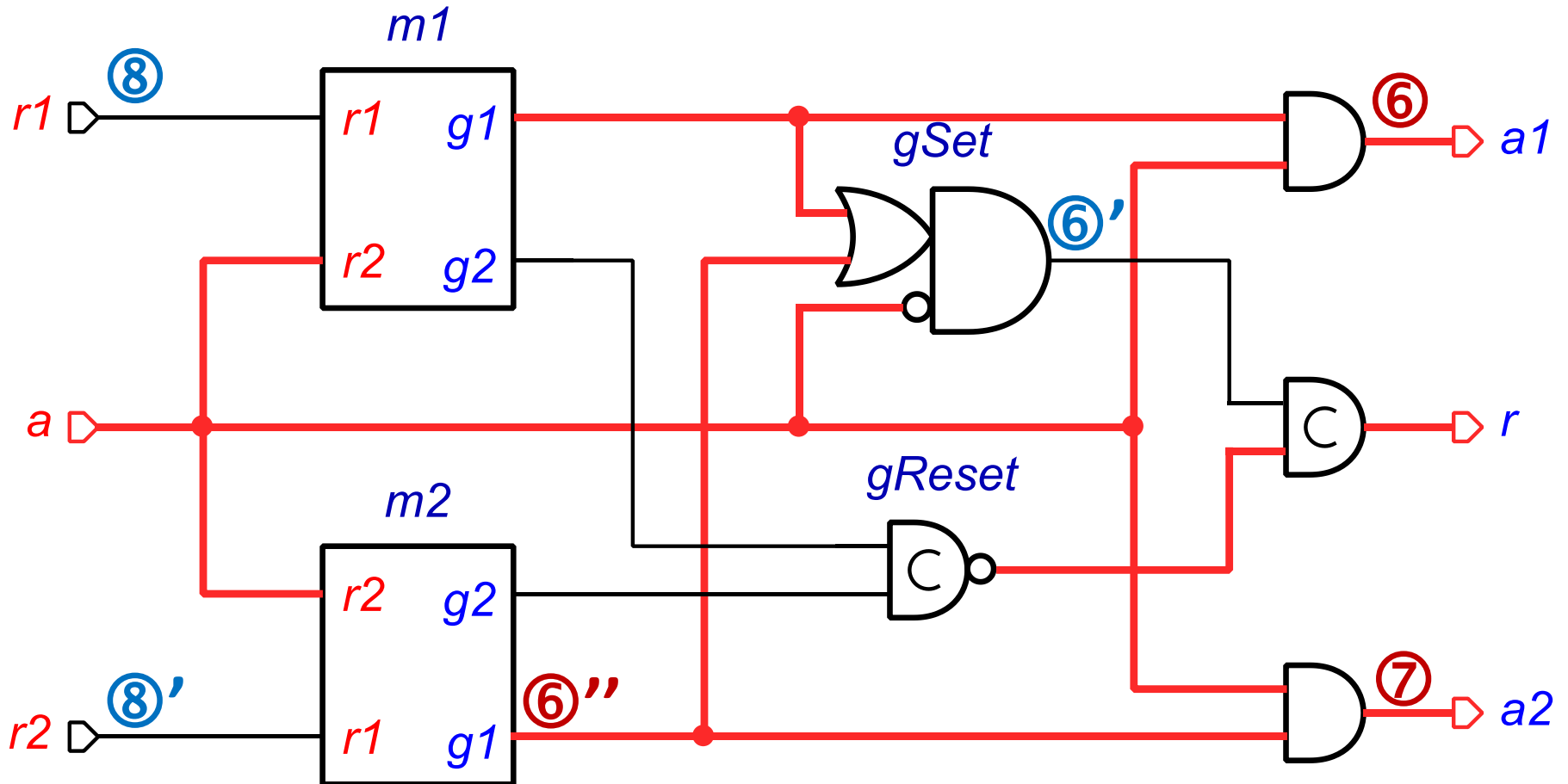
Scenario 2: request $r2$ wins the arbitration

Simplified (hacked up) circuit



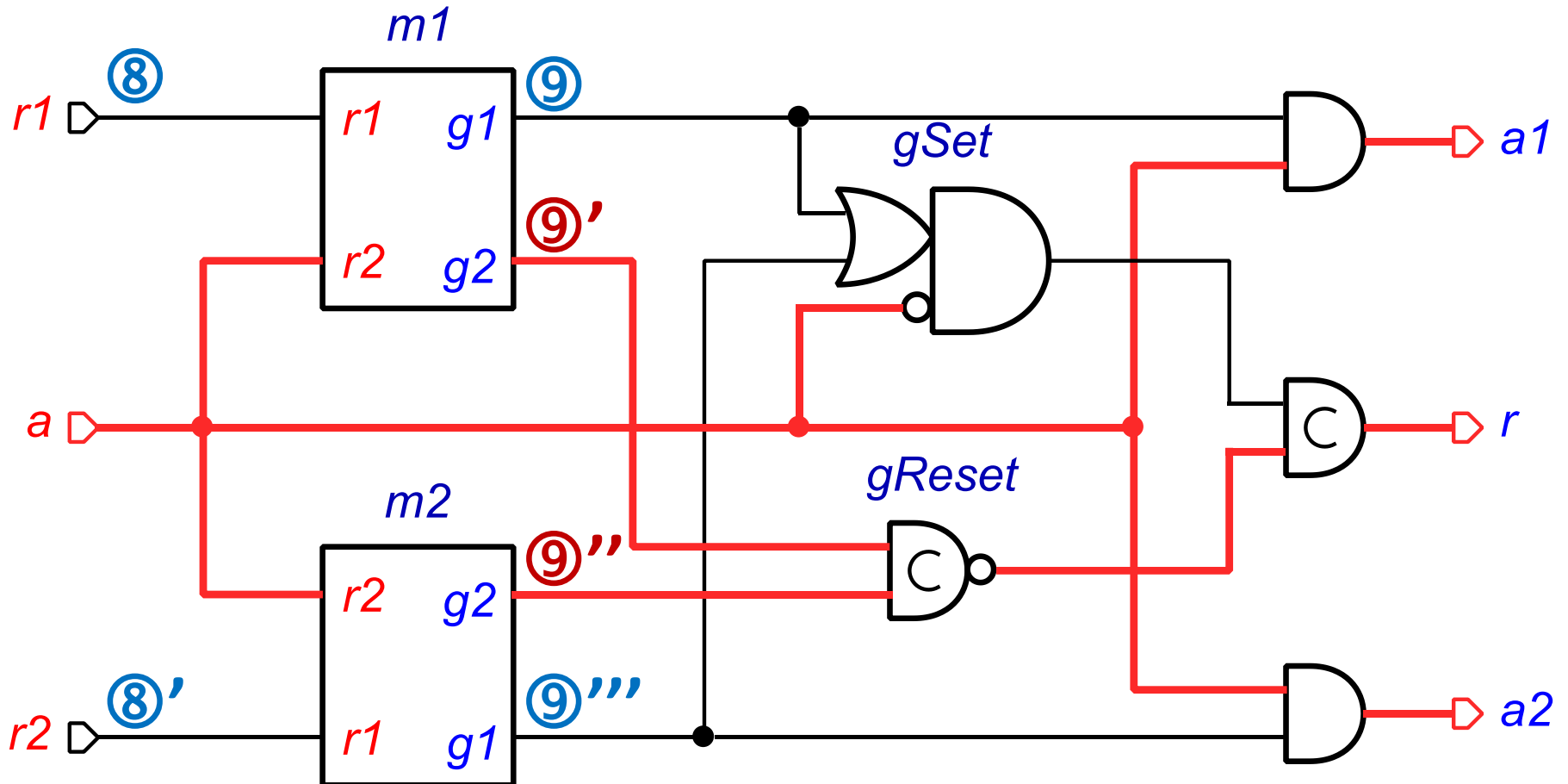
Scenario 2: request $r2$ wins the arbitration

Simplified (hacked up) circuit



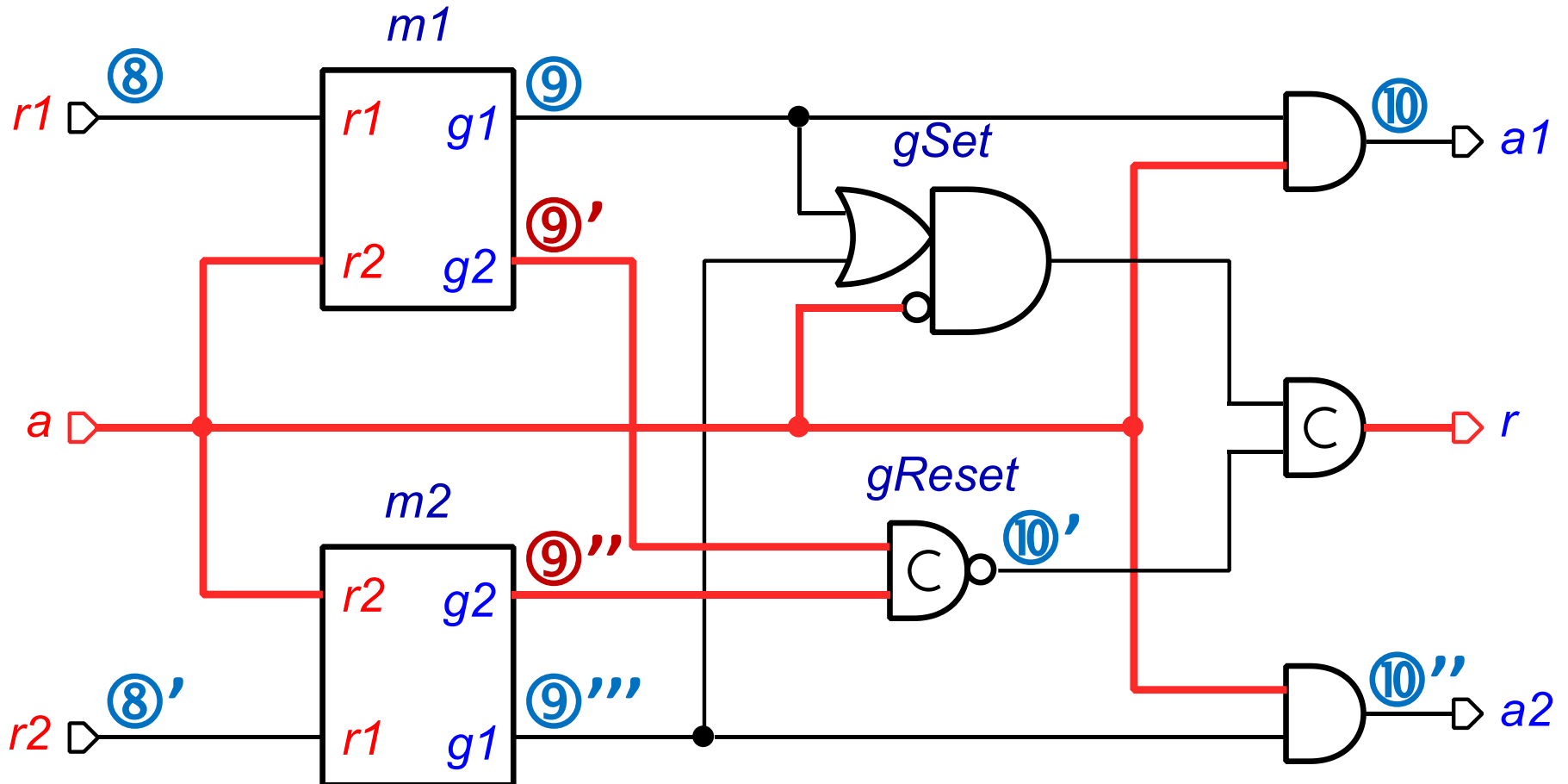
Scenario 2: request $r2$ wins the arbitration

Simplified (hacked up) circuit



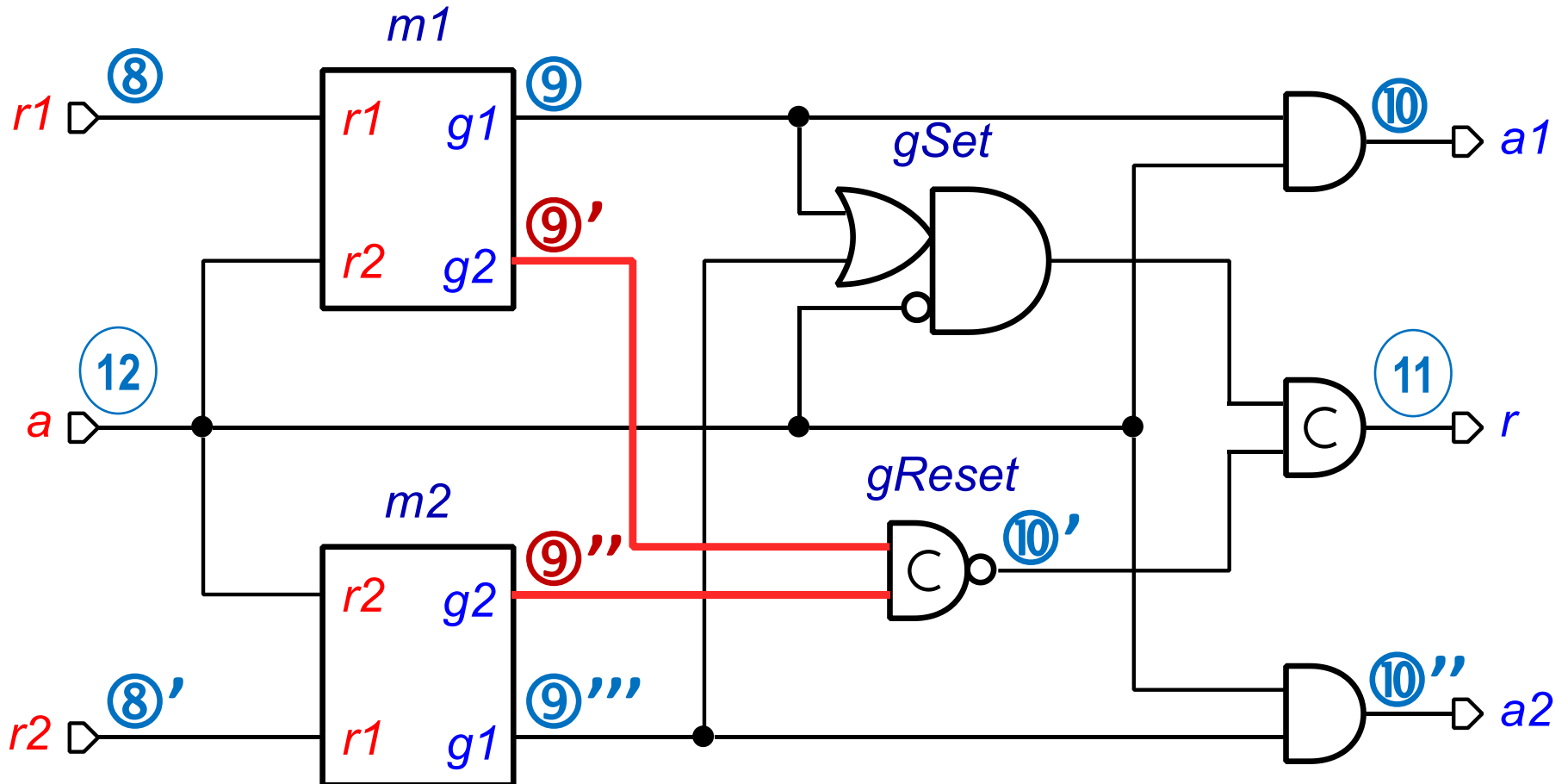
Scenario 2: request $r2$ wins the arbitration

Simplified (hacked up) circuit



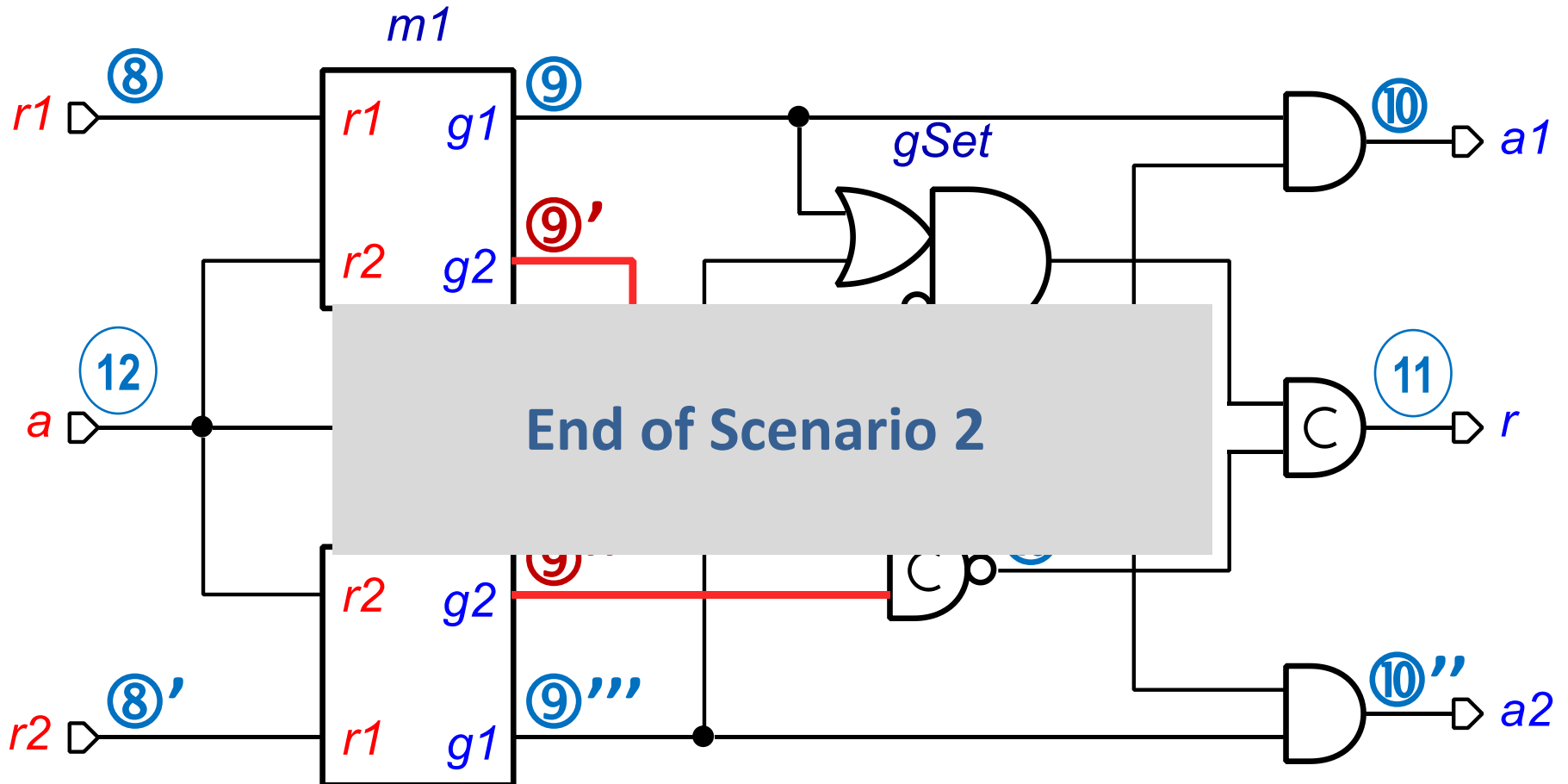
Scenario 2: request $r2$ wins the arbitration

Simplified (hacked up) circuit



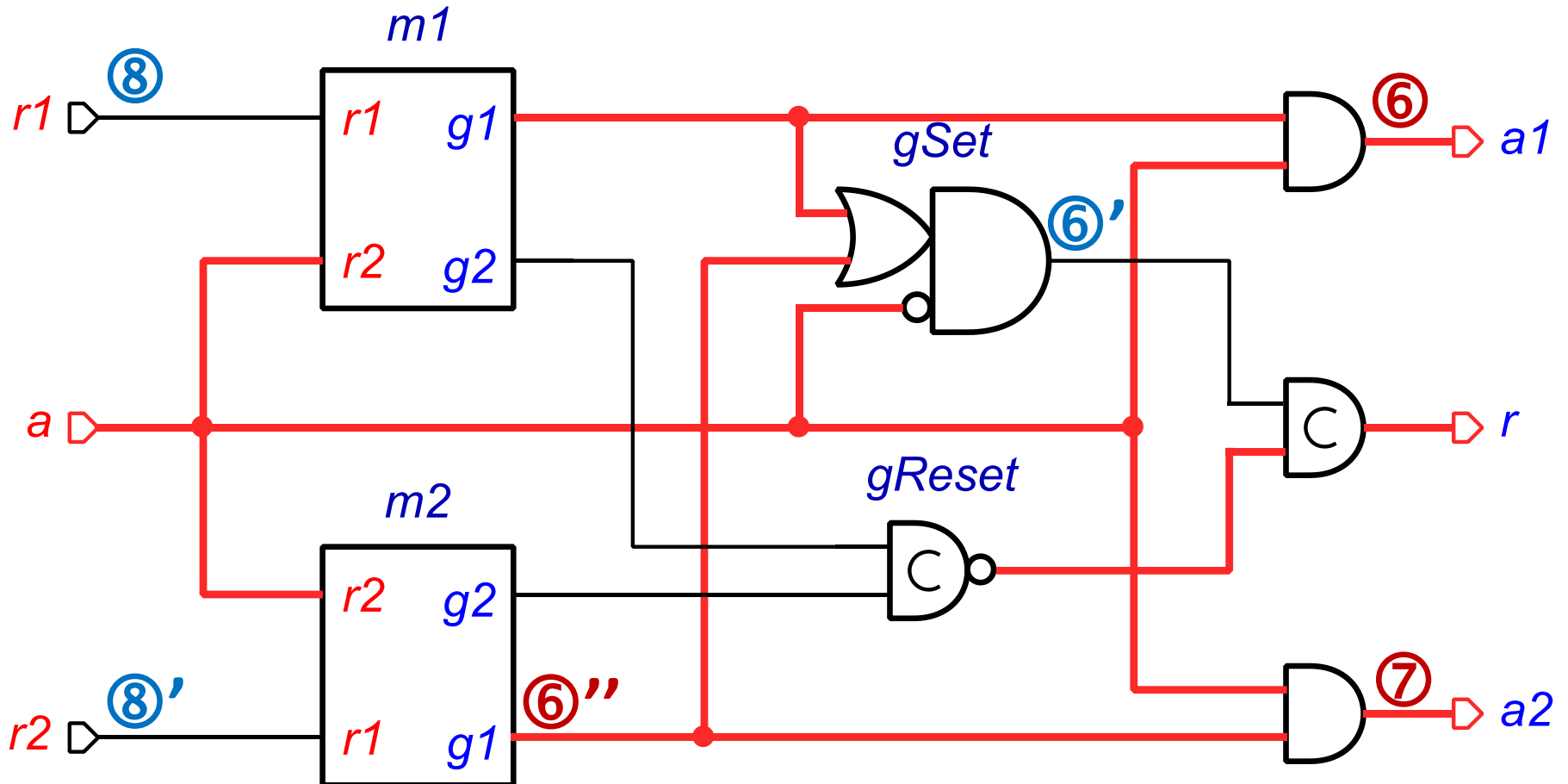
Scenario 2: request $r2$ wins the arbitration

Simplified (hacked up) circuit



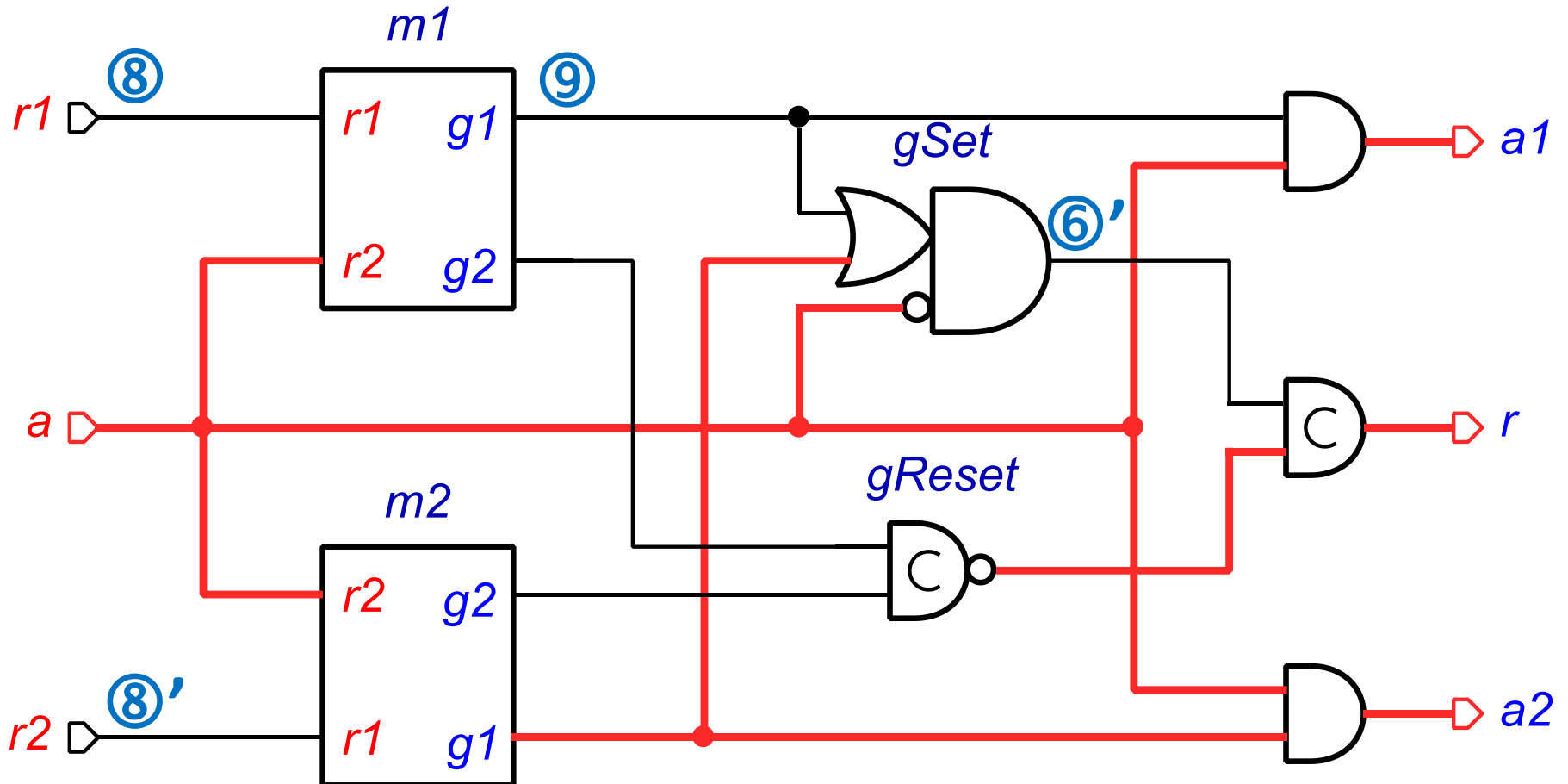
Scenario 2: request $r2$ wins the arbitration

Simplified (hacked up) circuit



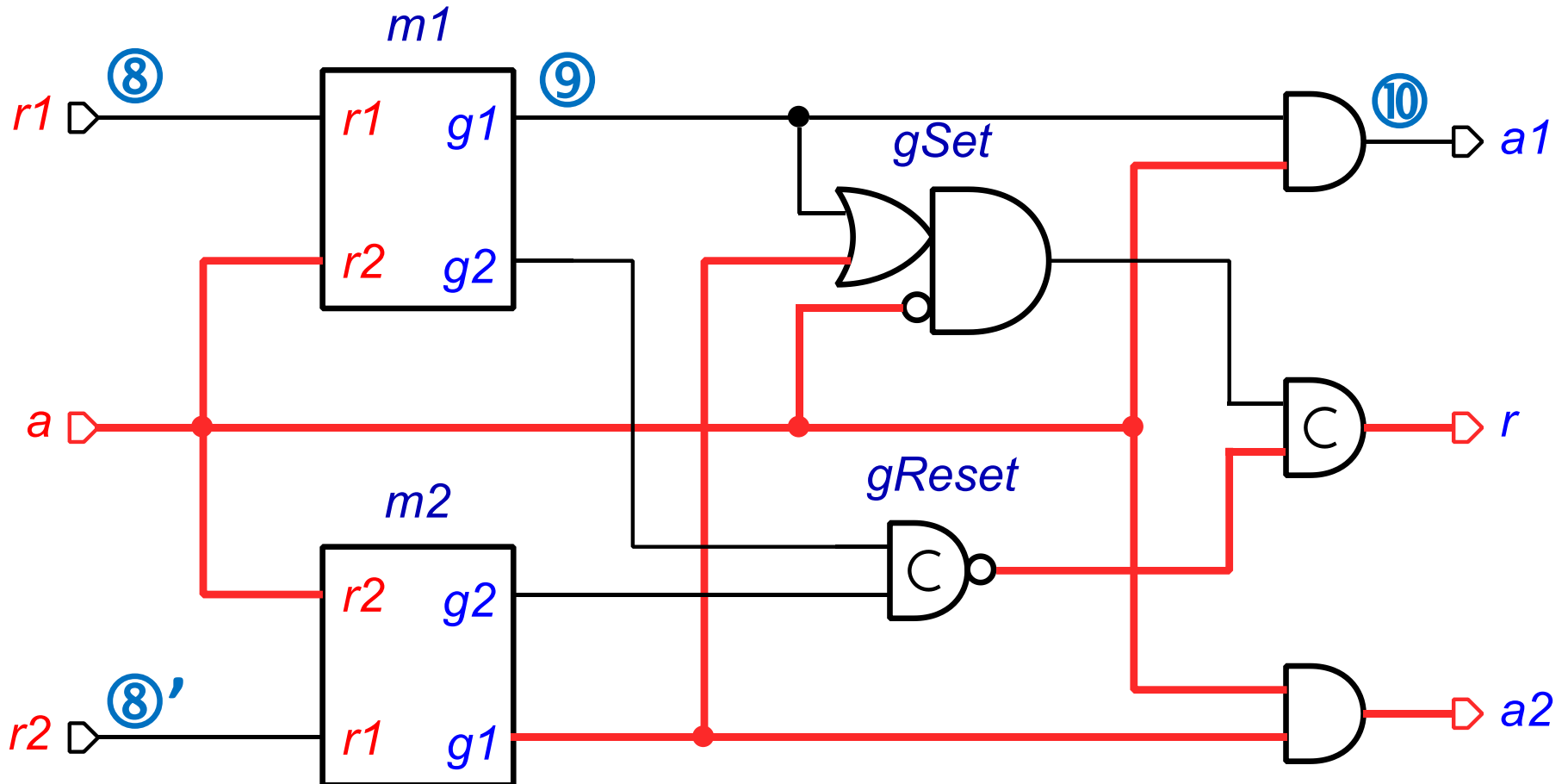
Scenario 3: sequential bundling of requests

Simplified (hacked up) circuit



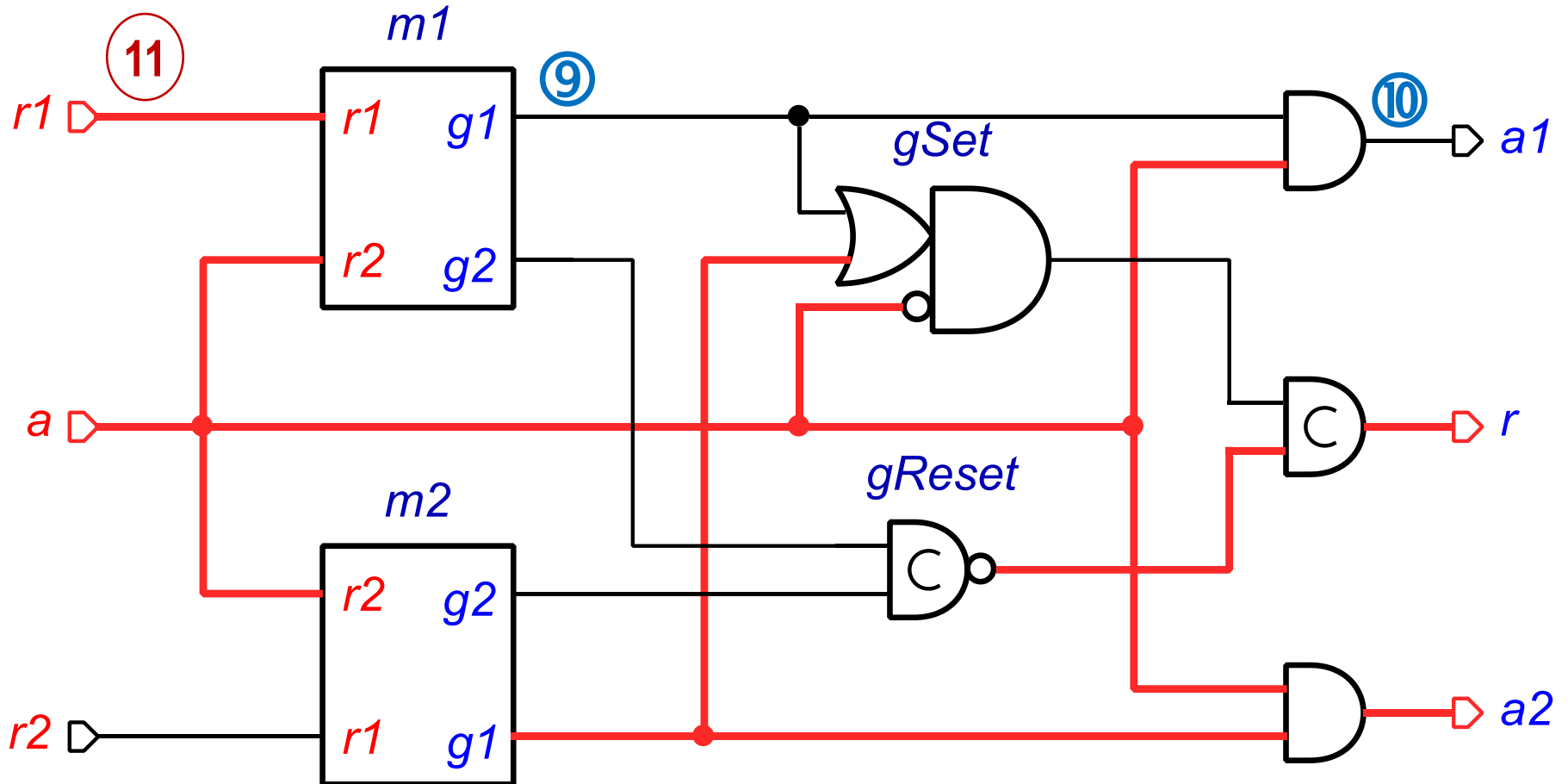
Scenario 3: sequential bundling of requests

Simplified (hacked up) circuit



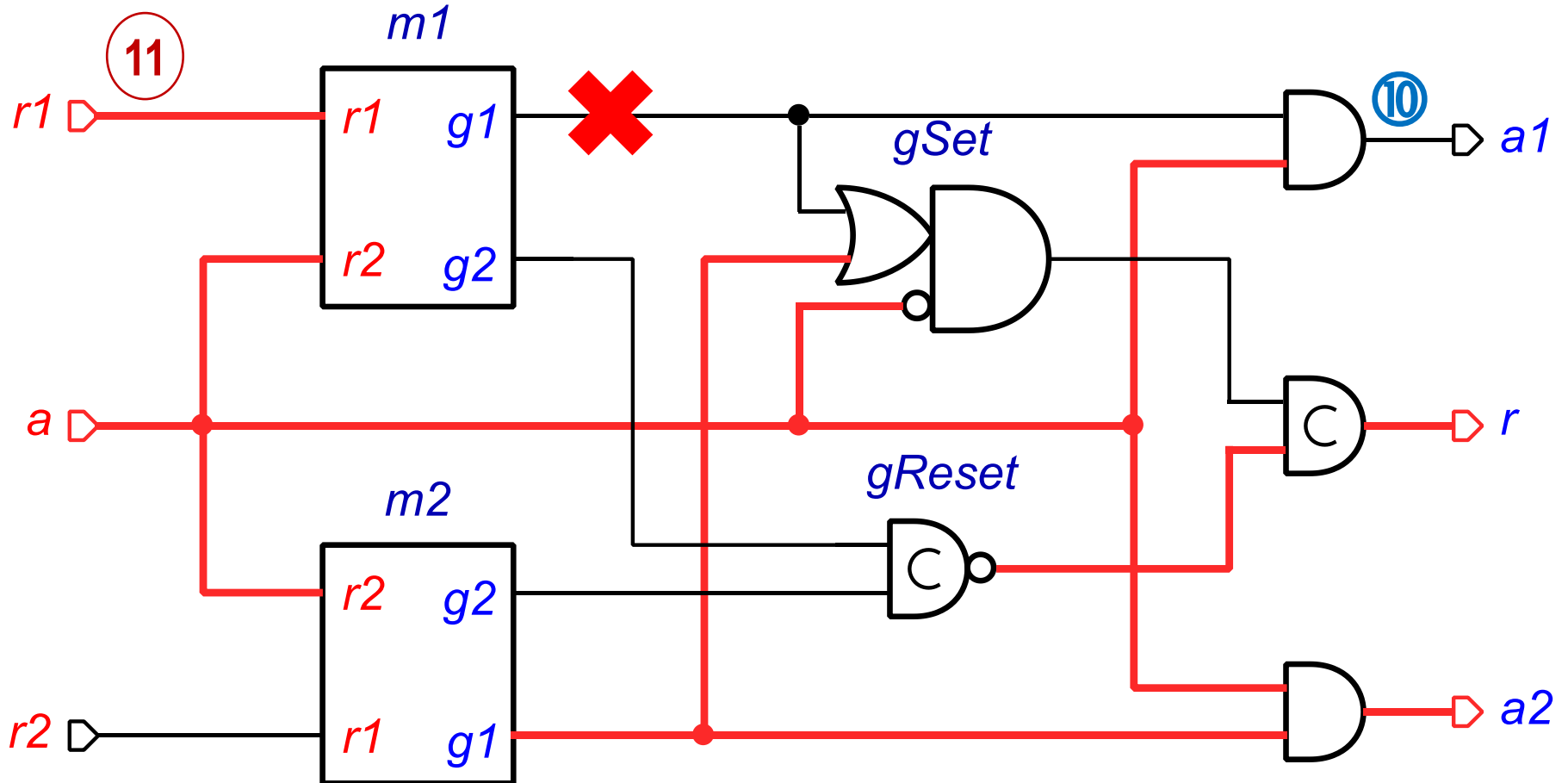
Scenario 3: sequential bundling of requests

Simplified (hacked up) circuit



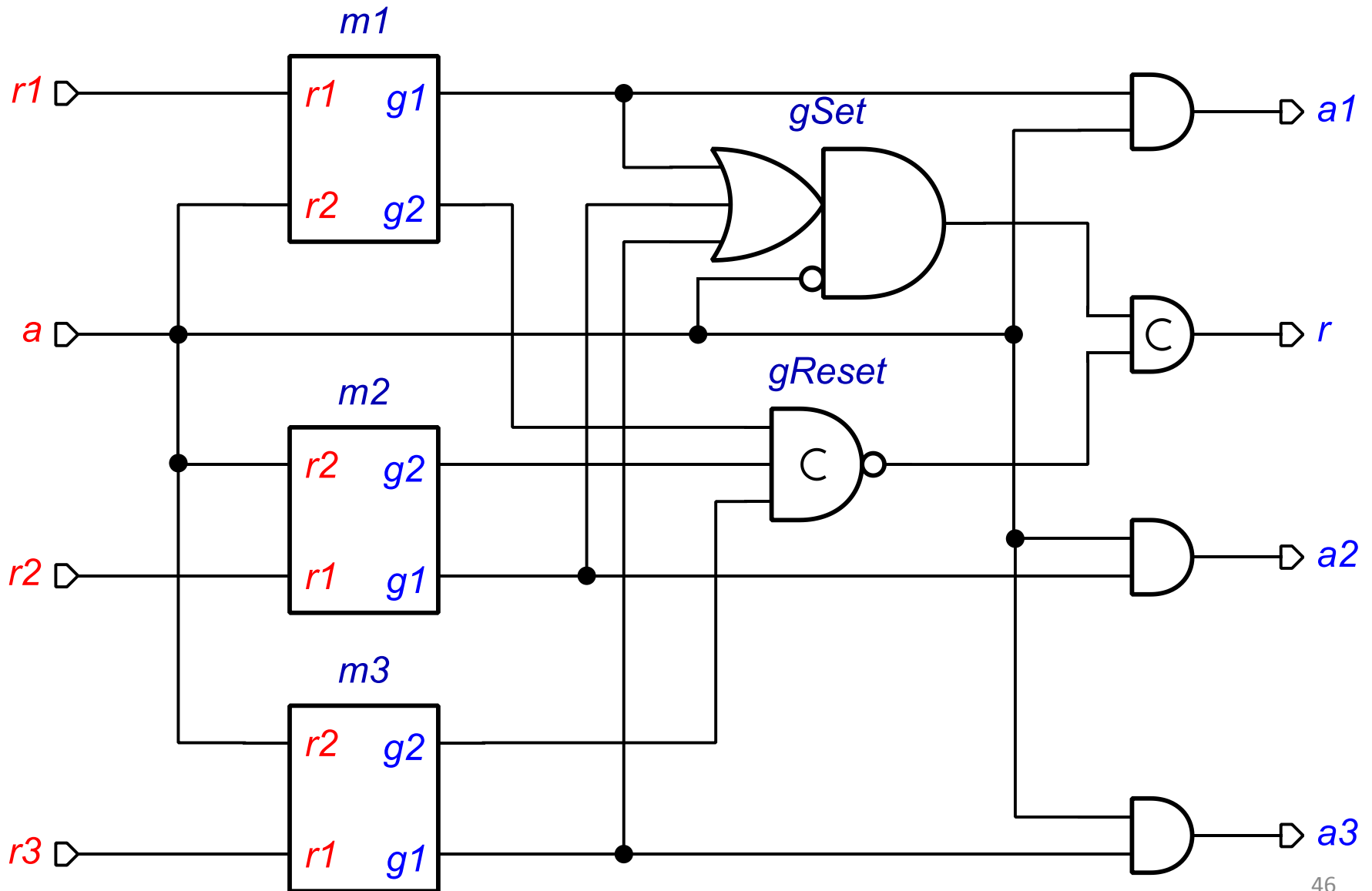
Scenario 3: sequential bundling of requests

Simplified (hacked up) circuit

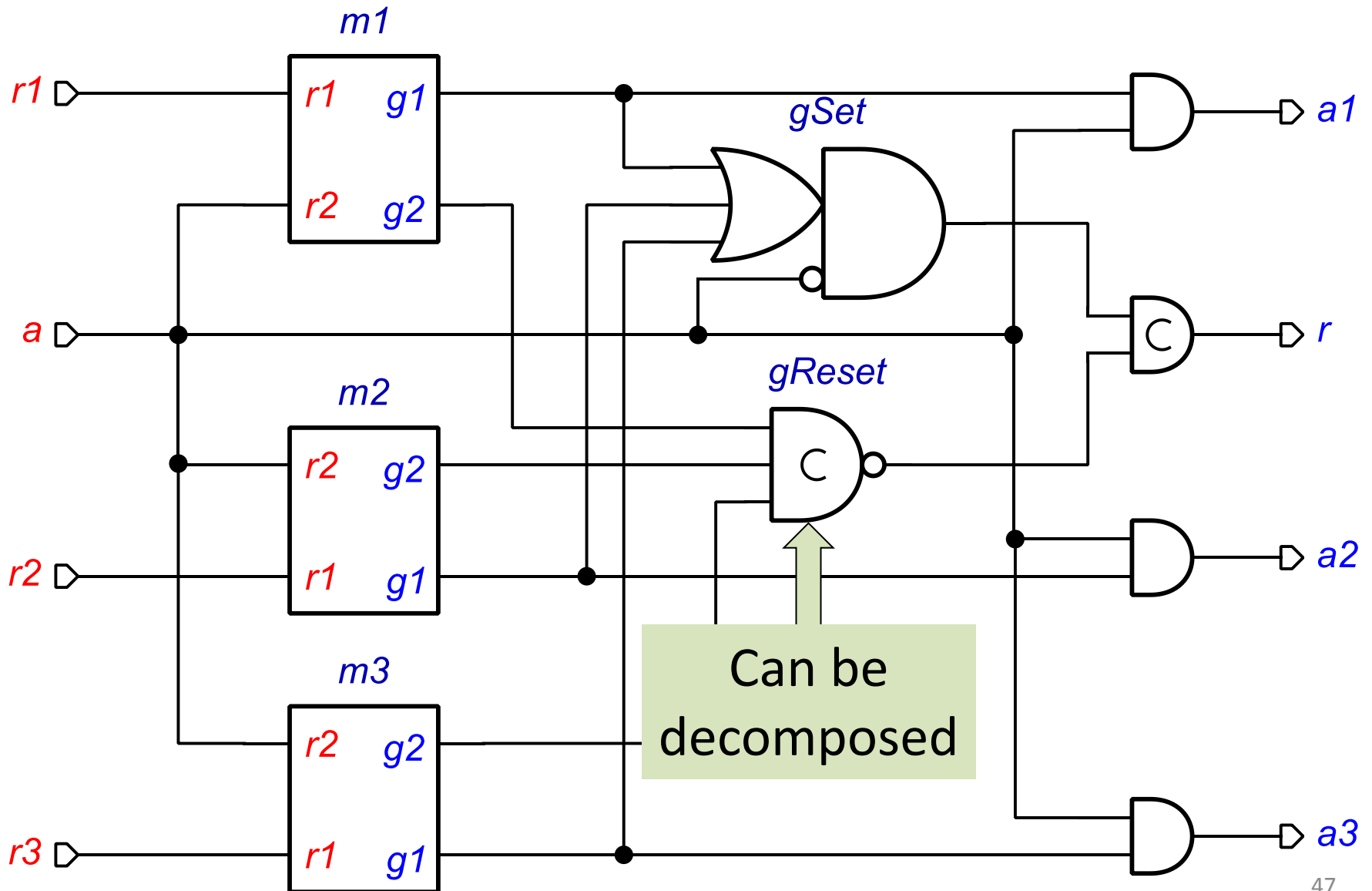


Fair mutexes do not permit sequential bundling

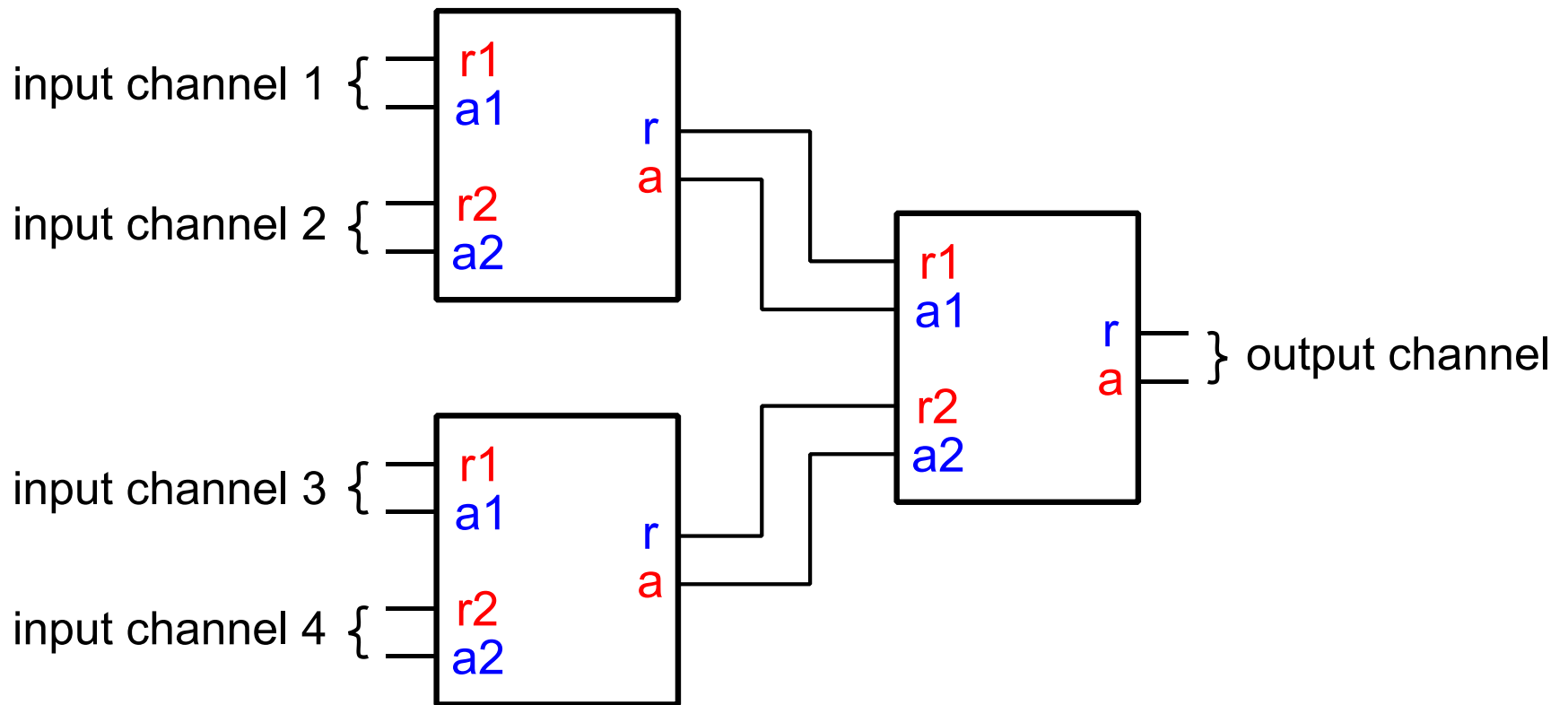
Scaling to more inputs



Scaling to more inputs



Scaling to more inputs



Conclusion

- New reusable asynchronous component – surprisingly difficult for just 3 handshakes!
- Fast implementation – no metastability on critical path
- Discovered *fairness-based optimisation*
- Scalable
- Formally verified using Workcraft and Versify
- To be integrated into a real multiphase buck

- Challenge for asynchronous community:
*Design OM in a non-monolithic way
(how to design it without a miracle?)*

Thank you!

Opportunistic bundling of questions is encouraged (fairness assumption on the session chair to prevent sequential bundling) 😊