On the Power of Weaker Pairwise Interaction: Fault-Tolerant Simulation of Population Protocols

ICDCS 2017

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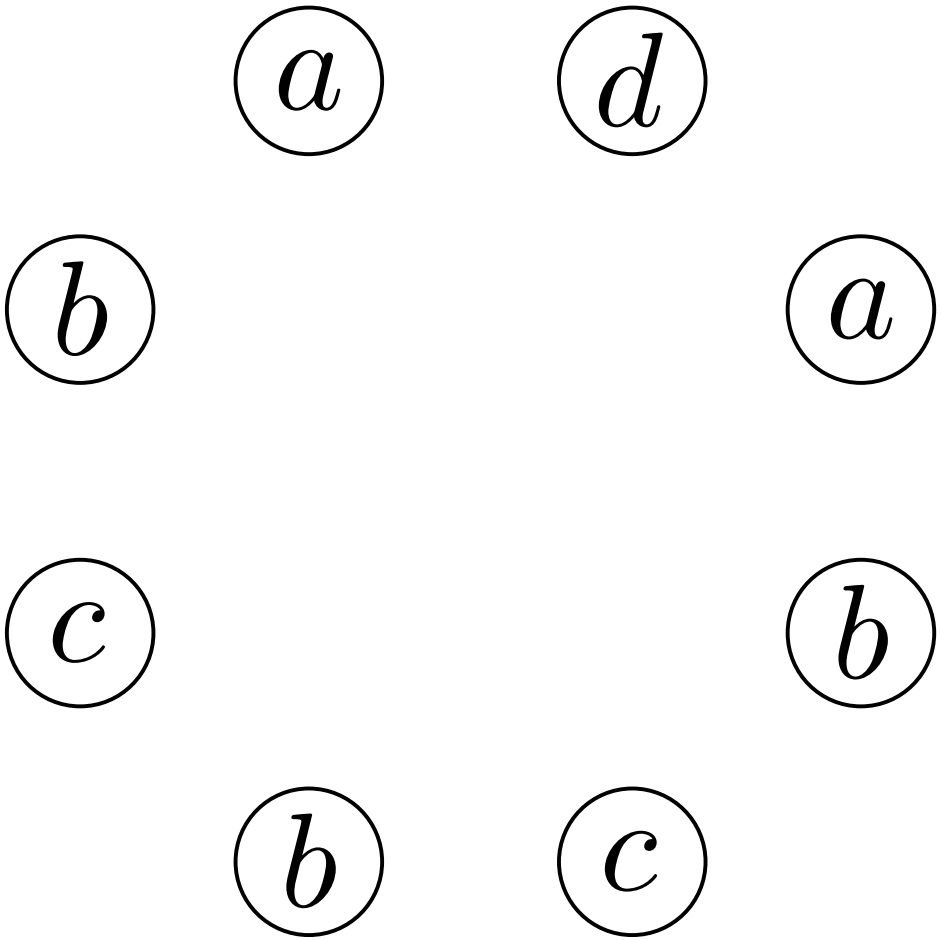
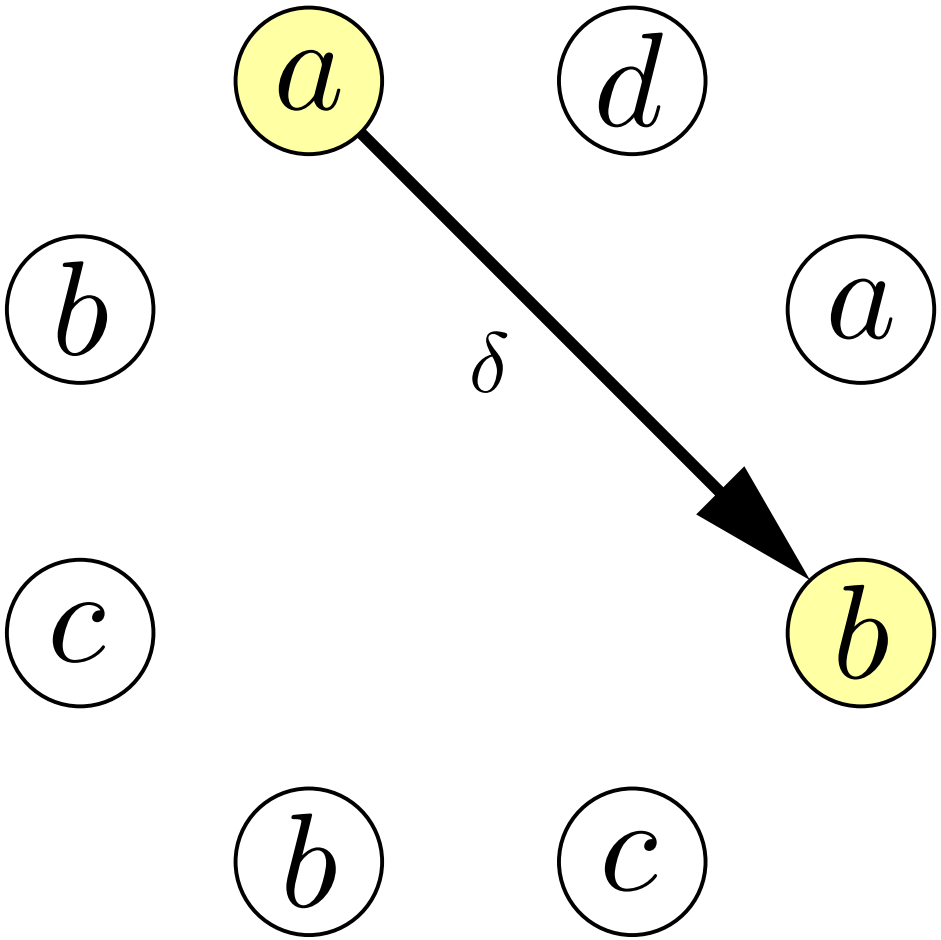
Population Protocols



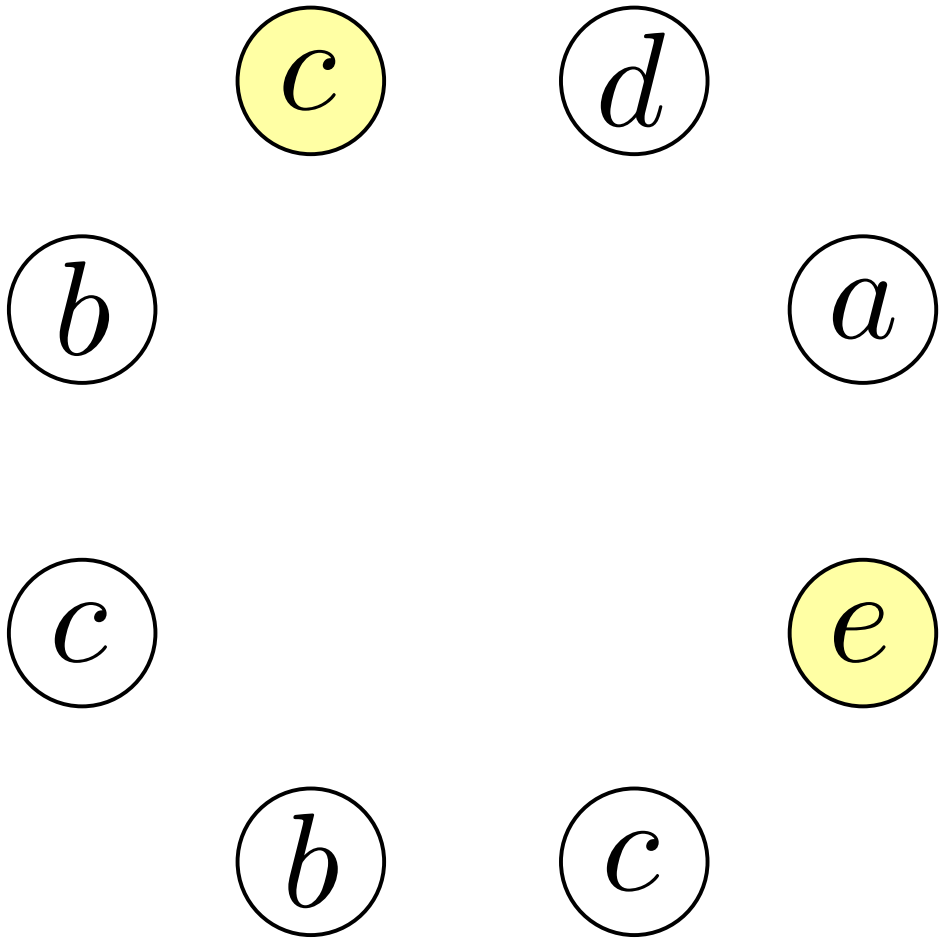
Setting: a set of finite-state agents.

Population Protocols



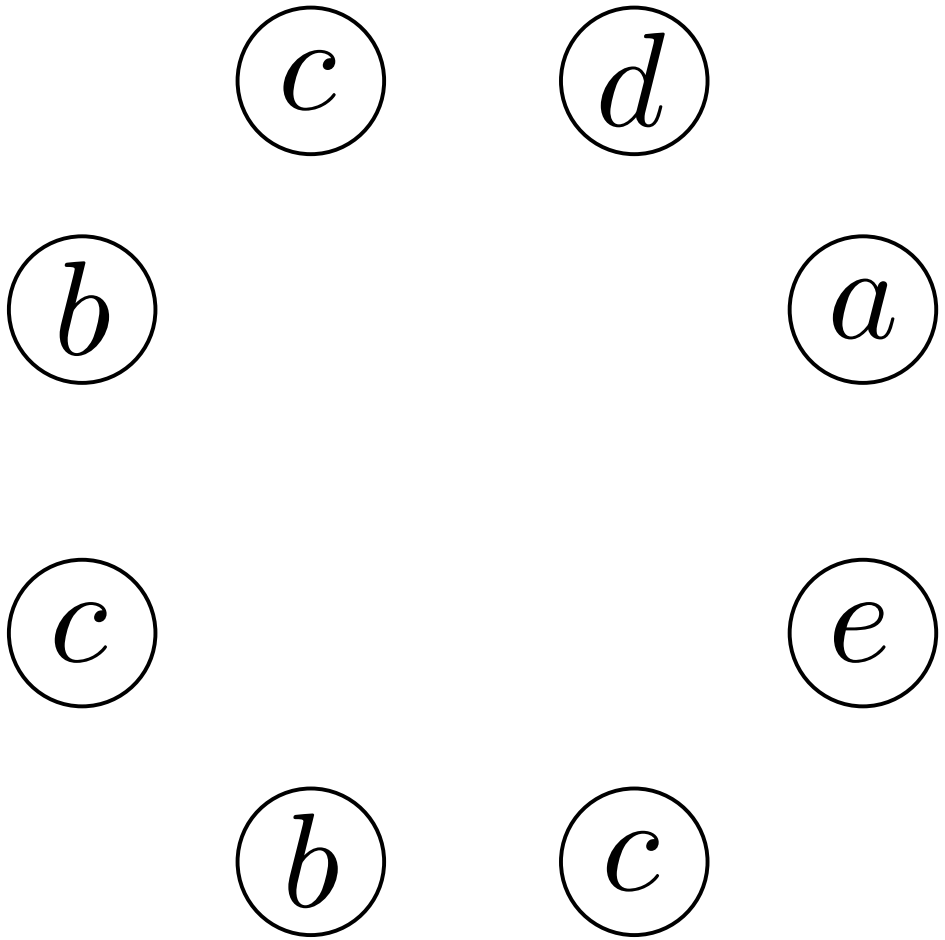
Pairs of agents interact in a non-deterministic order...

Population Protocols



...and change states according to a transition function.

Population Protocols



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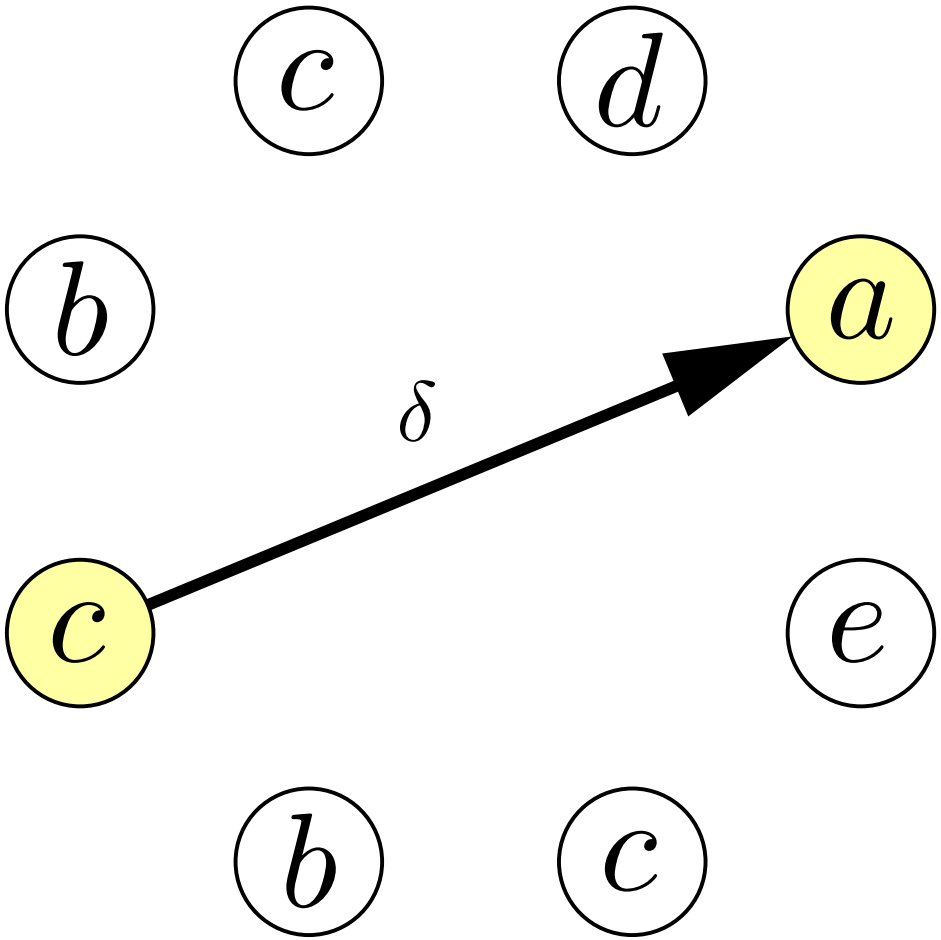
Population Protocols



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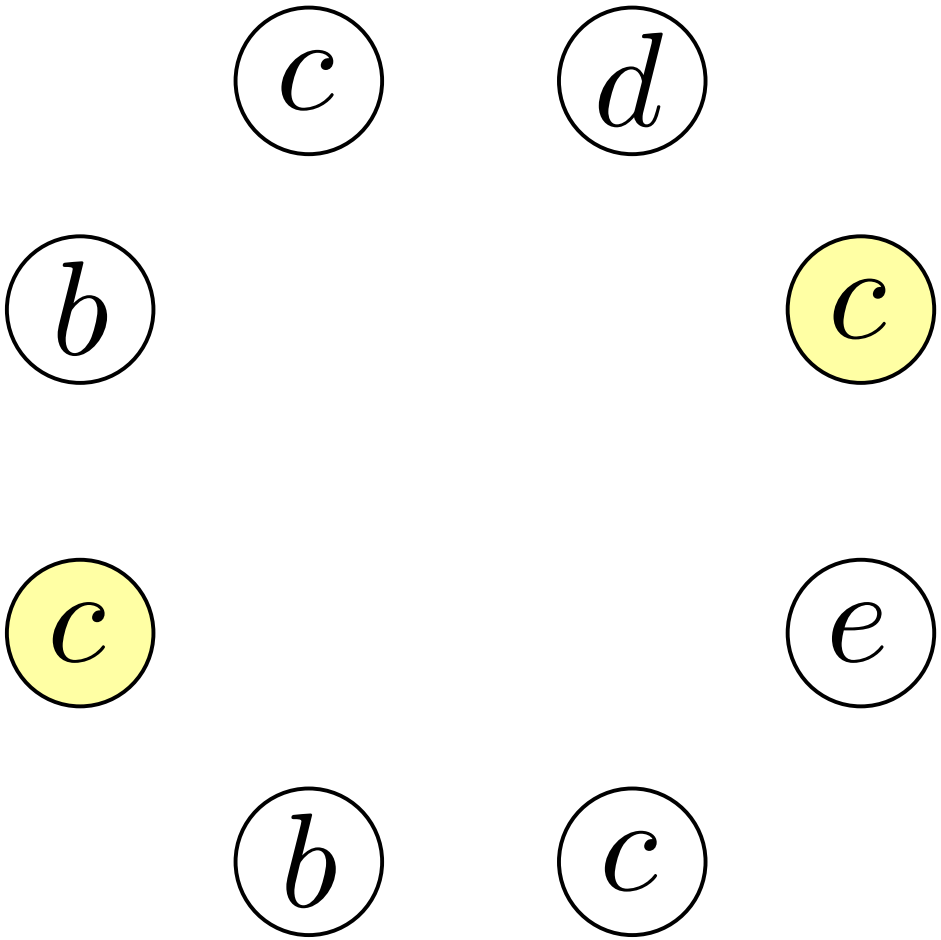
Population Protocols



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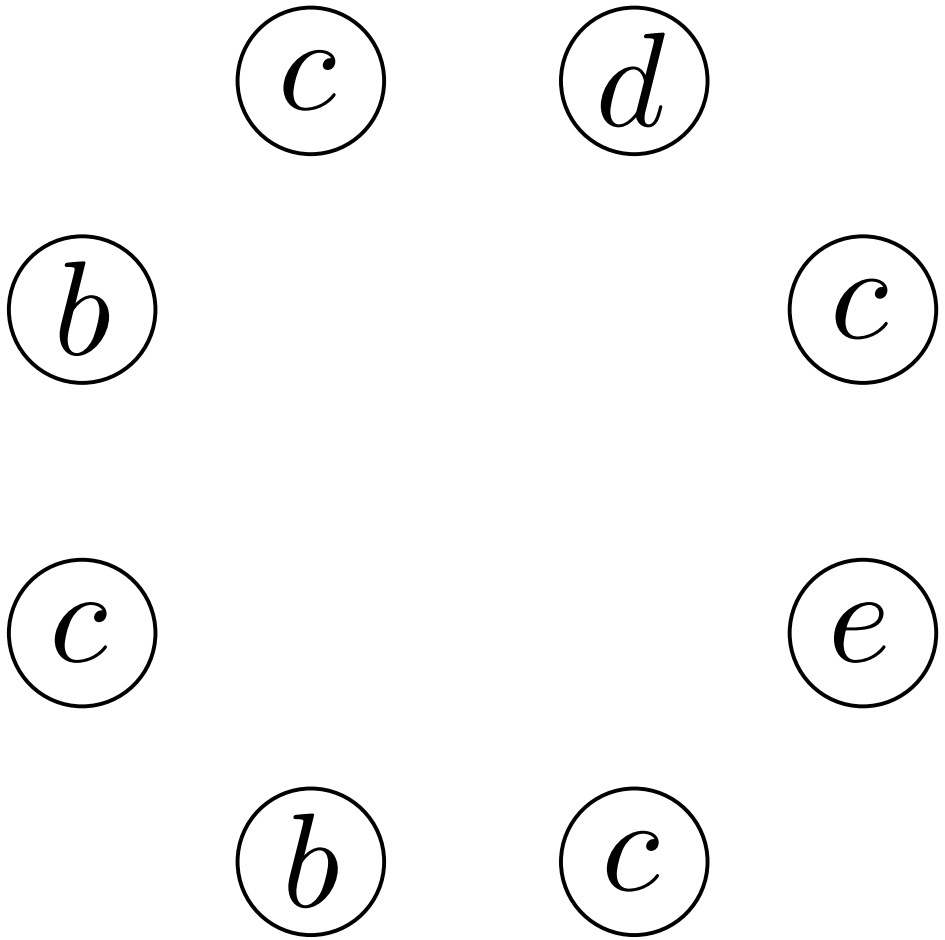
Population Protocols



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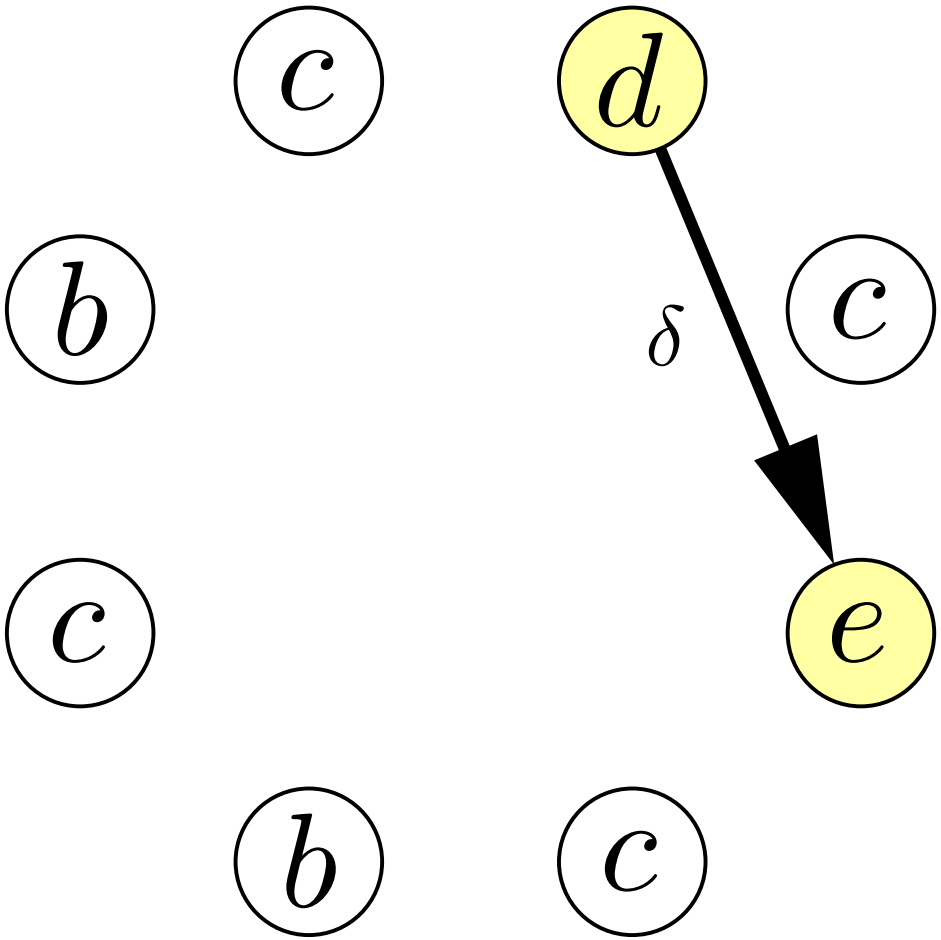
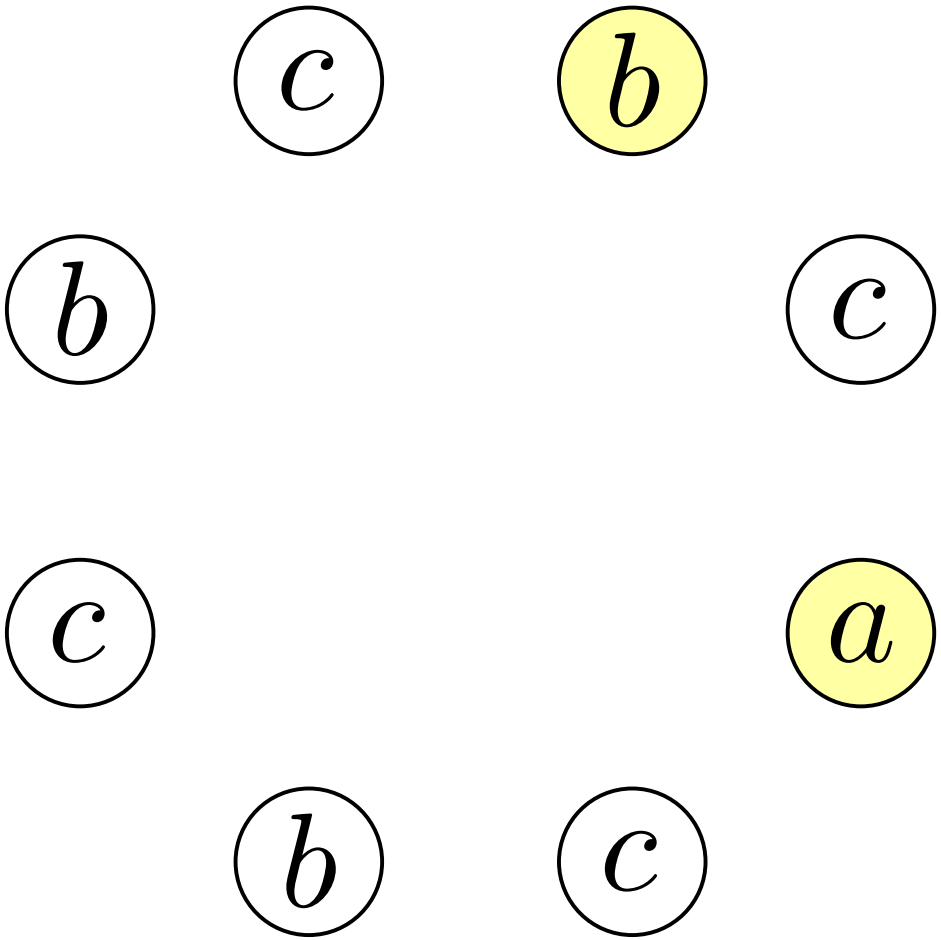
Population Protocols



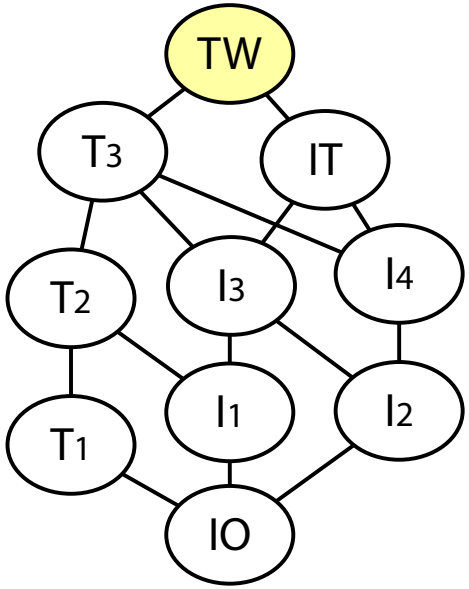
...and change states according to a transition function.

Population Protocols



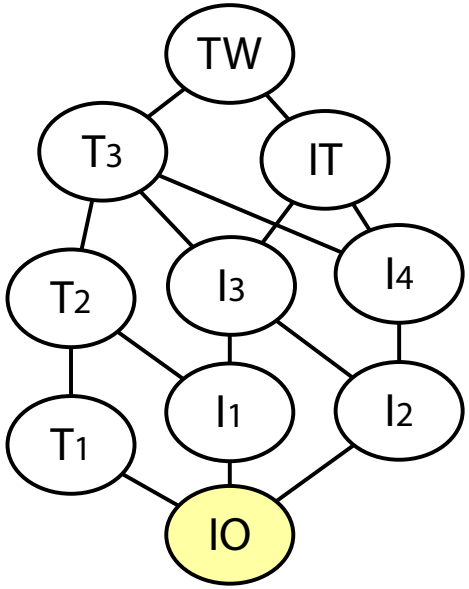
...and change states according to a transition function.

One-way models and omission faults



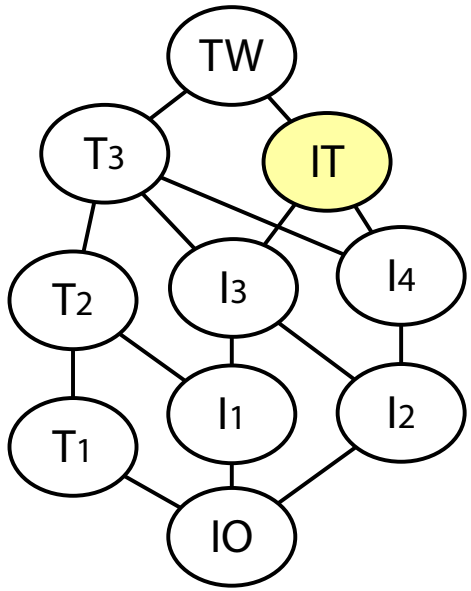
The traditional interaction model is called **Two-Way**.

One-way models and omission faults



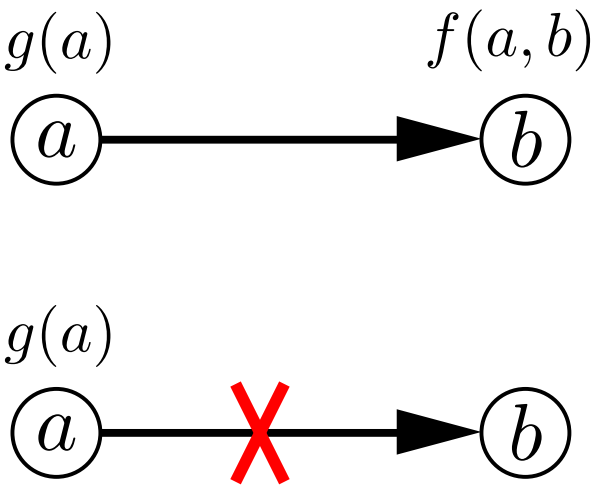
Immediate Observation: only the second agent transitions.

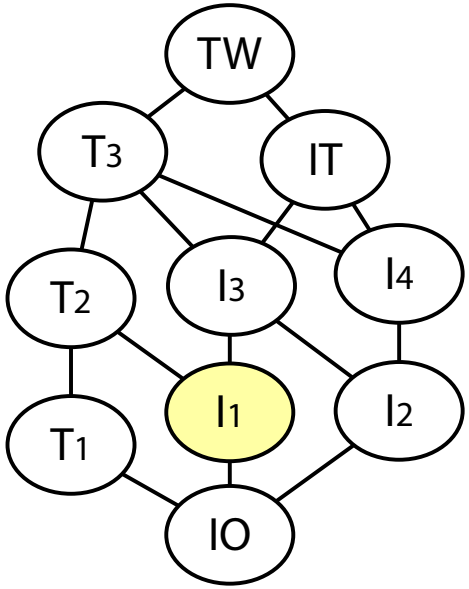
One-way models and omission faults



Immediate Transmission: the first agent detects *proximity*.

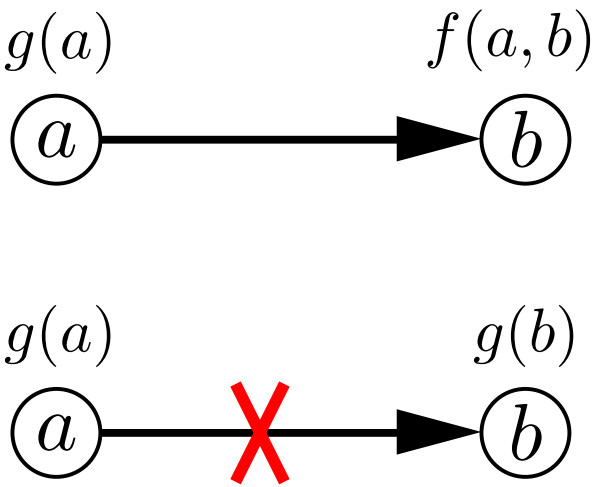
One-way models and omission faults

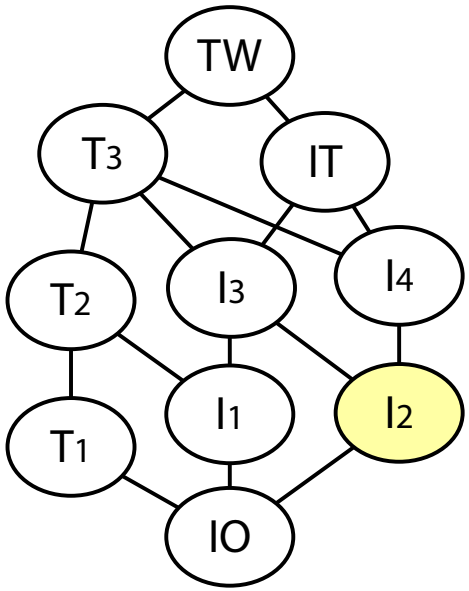




I_1: IT with omission faults, no detection.

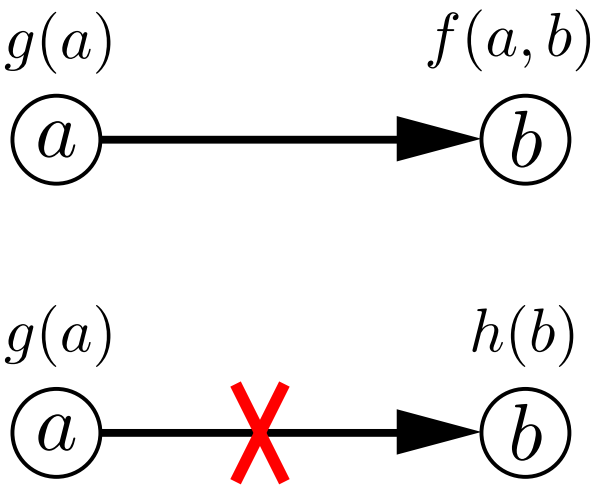
One-way models and omission faults

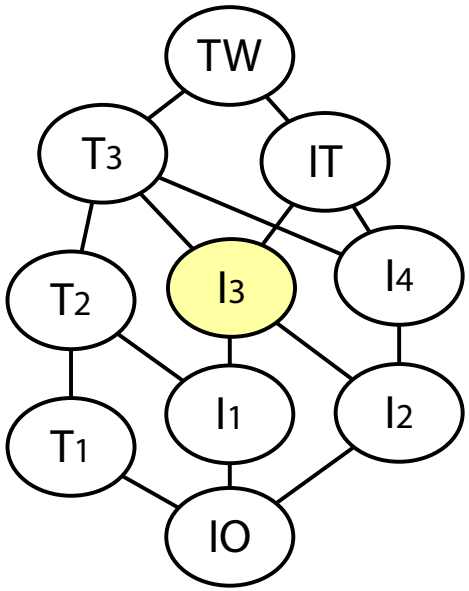




I_2: IT with omission faults, proximity detection.

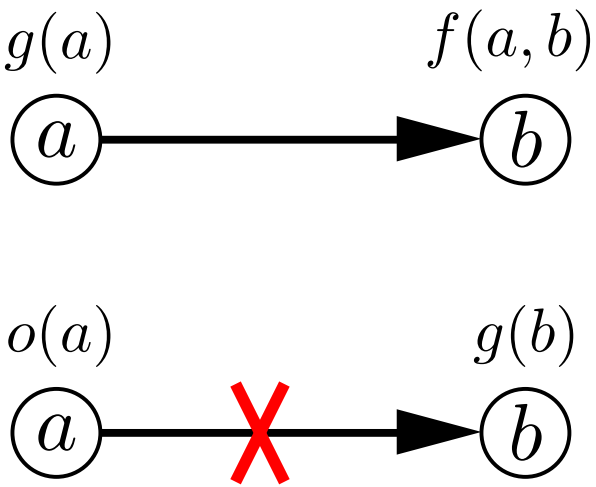
One-way models and omission faults

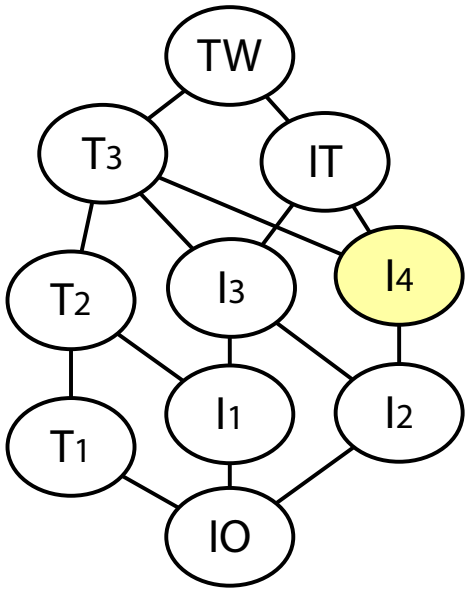




I_3: IT with omission faults, reactor-side omission detection.

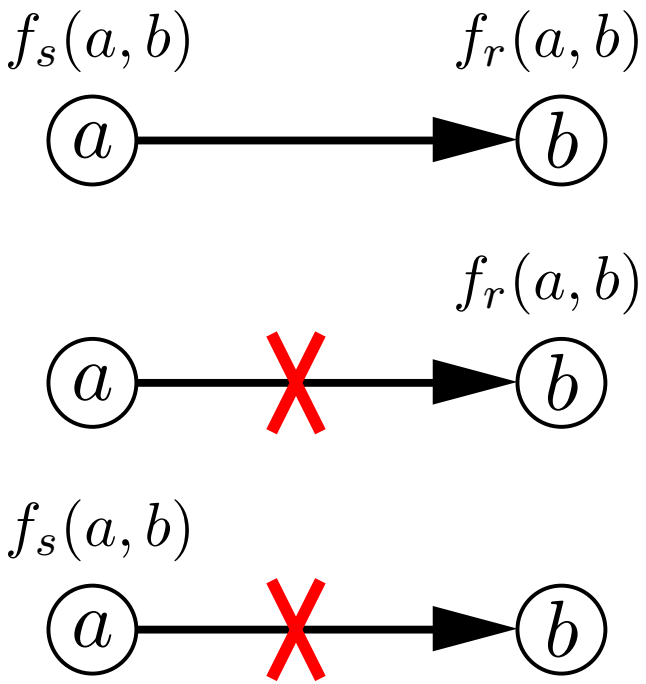
One-way models and omission faults

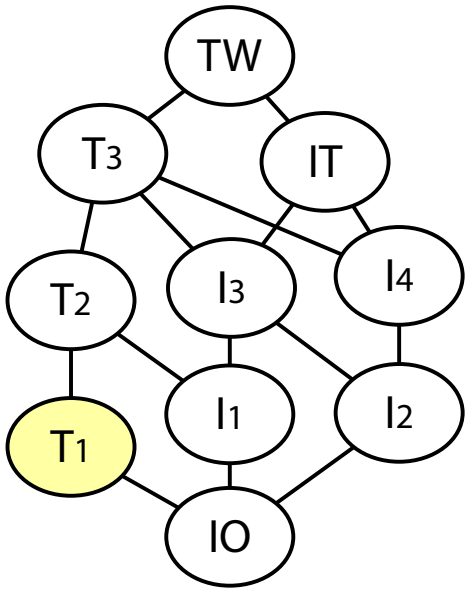




I_4: IT with omission faults, starter-side omission detection.

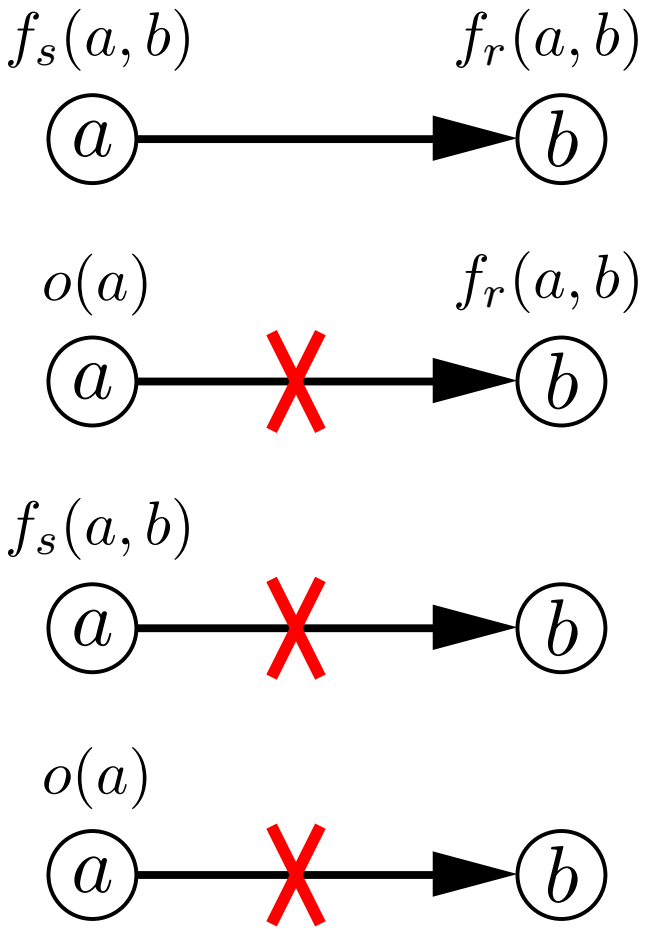
One-way models and omission faults

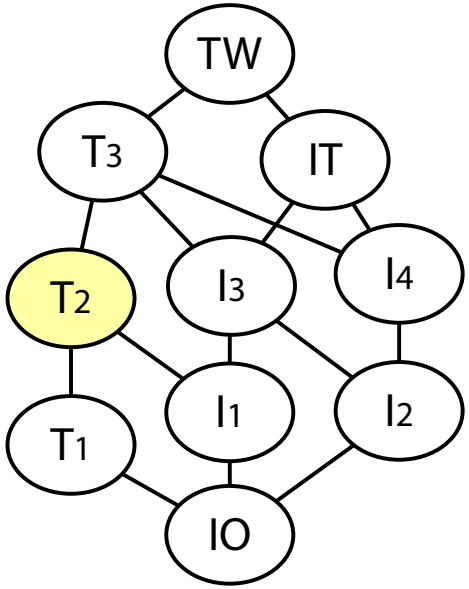




T_1: TW with omission faults, no detection.

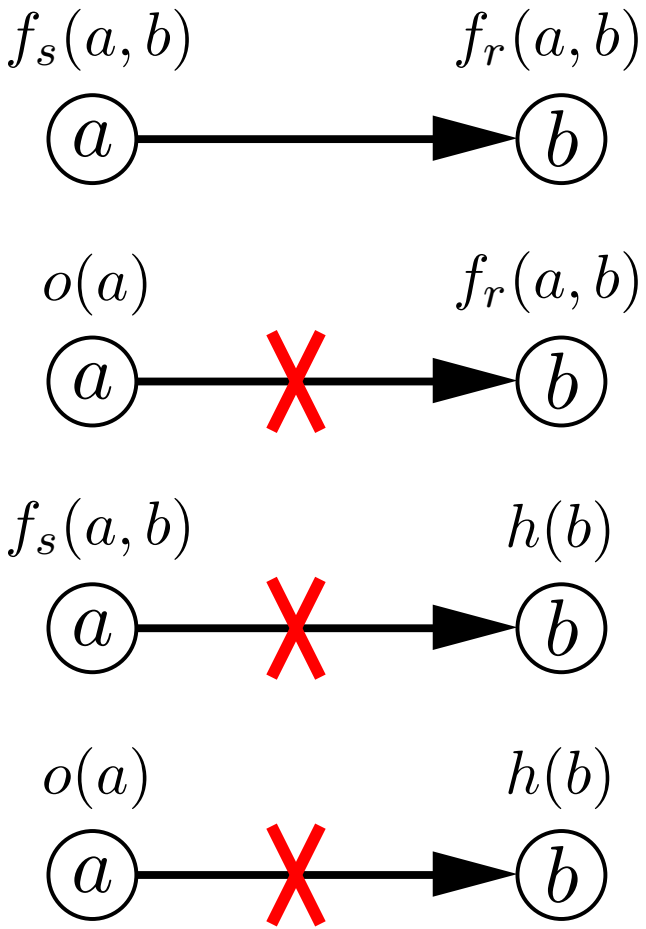
One-way models and omission faults

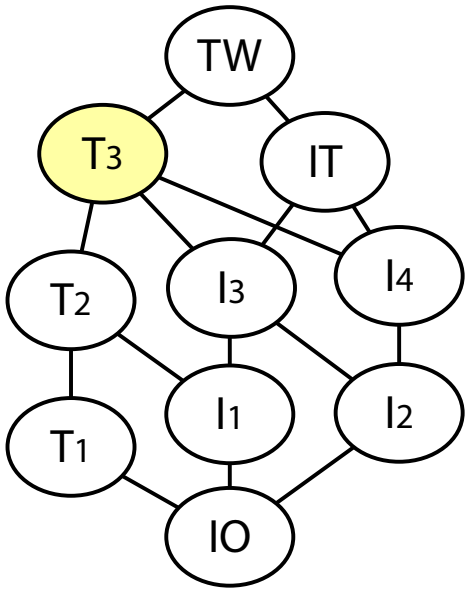




T_2: TW with omission faults, starter-side omission detection.

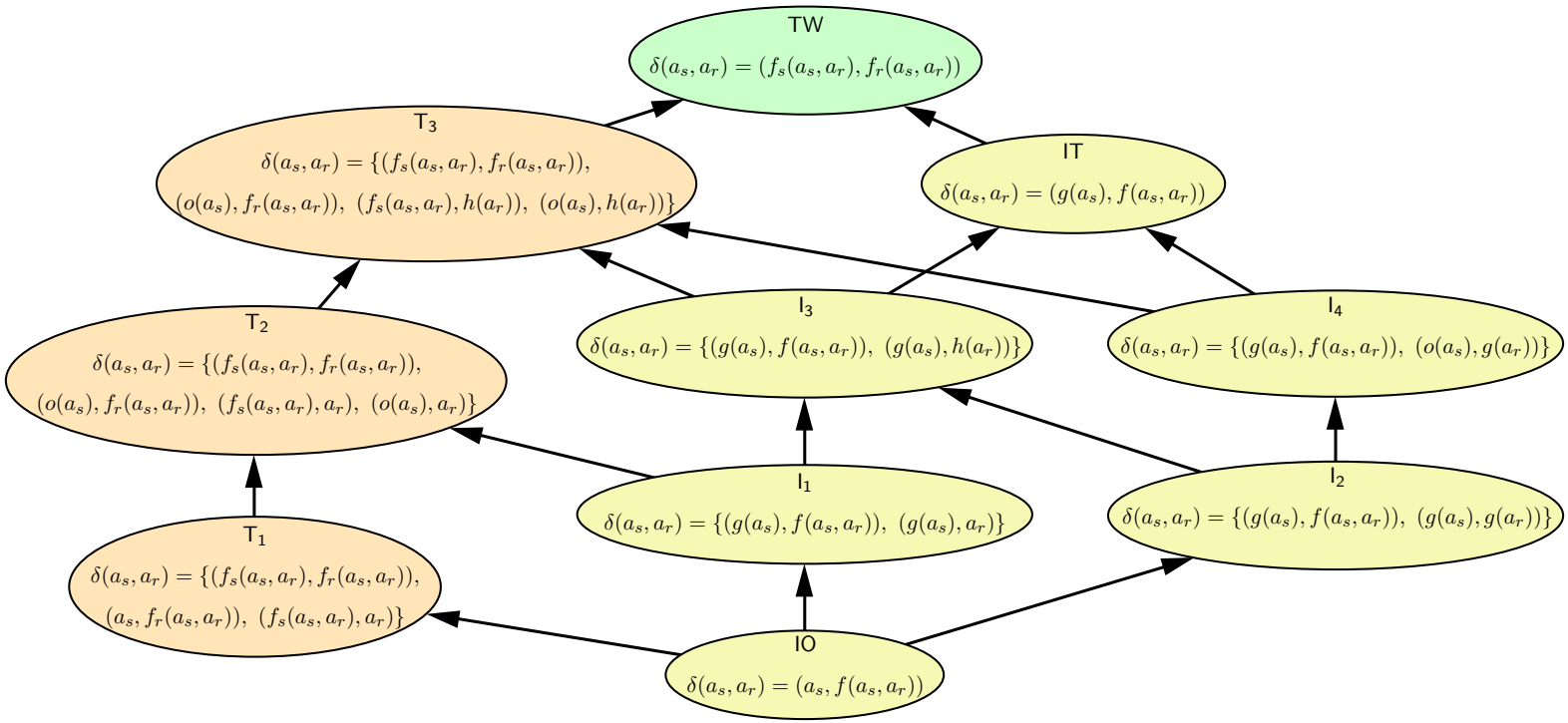
One-way models and omission faults





T_3: TW with omission faults, omission detection by both sides.

One-way models and omission faults

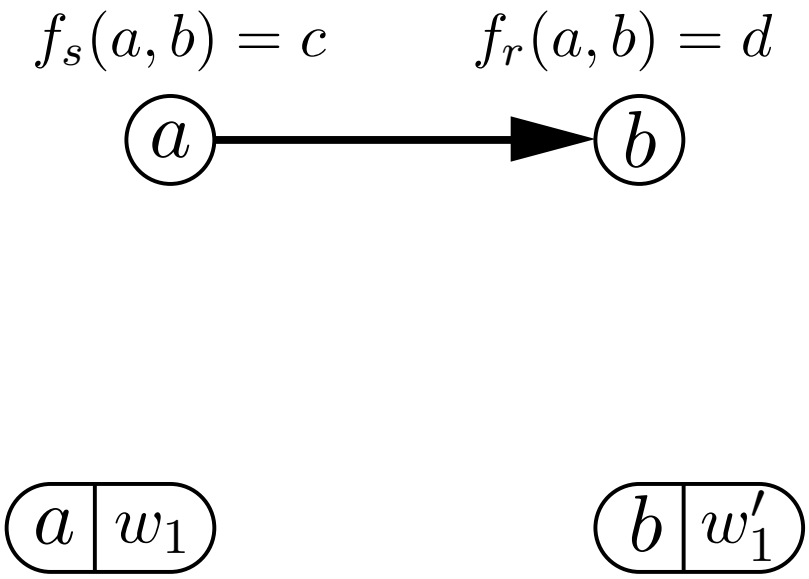


Theorem: all possible models obtained by combining one-way and two-way interactions with omission detection and proximity detection, starter-side or reactor-side, fall into one of these classes.

Simulating TW protocols with weaker ones

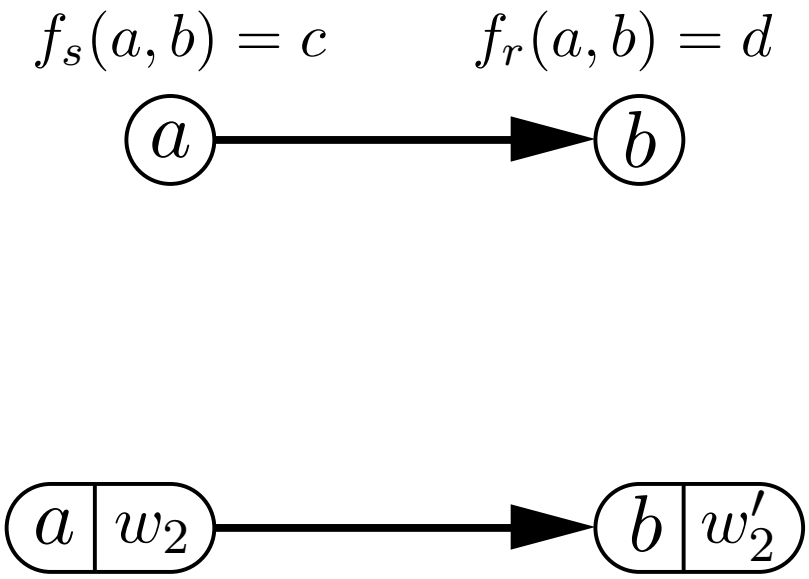
We seek to *simulate* two-way interactions in weaker models.

Simulating TW protocols with weaker ones



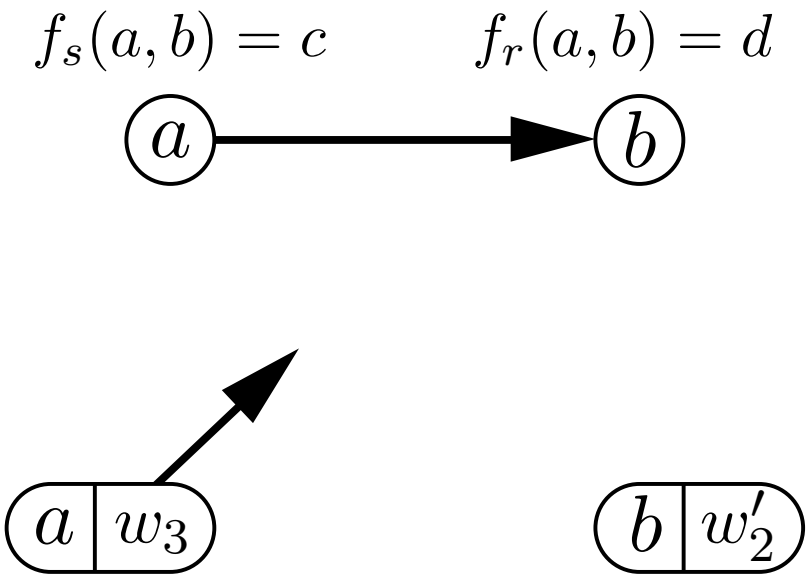
The simulating agents have a *simulated state* and a *work state*.

Simulating TW protocols with weaker ones



Typically, an interaction determines a change in the work state.

Simulating TW protocols with weaker ones



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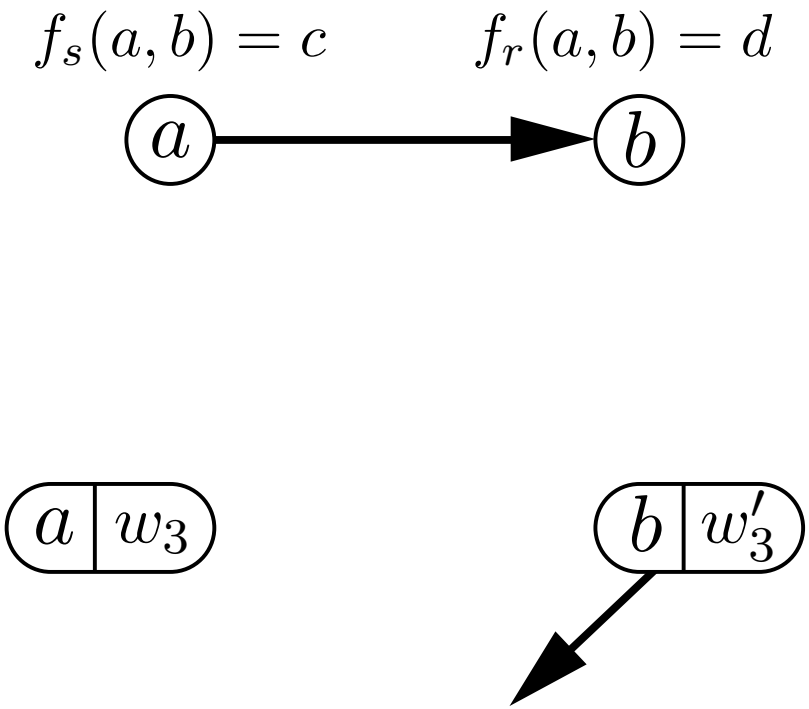

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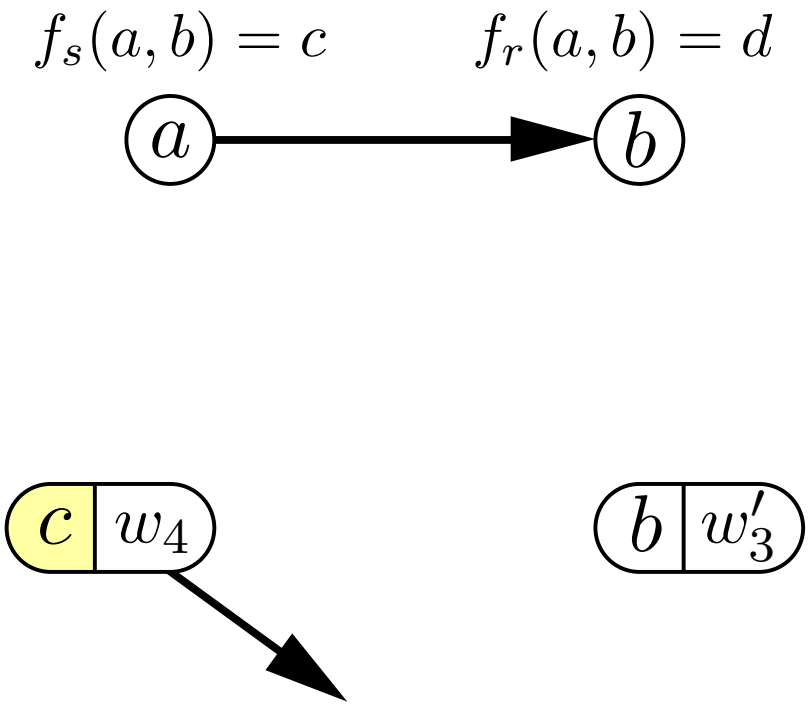
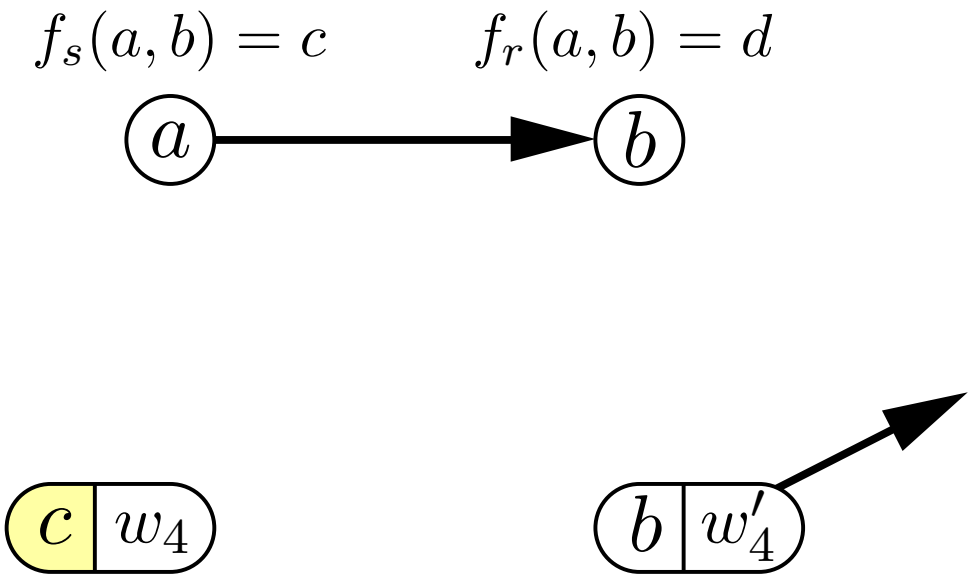


Occasionally, changes in the simulated state may occur.

Simulating TW protocols with weaker ones



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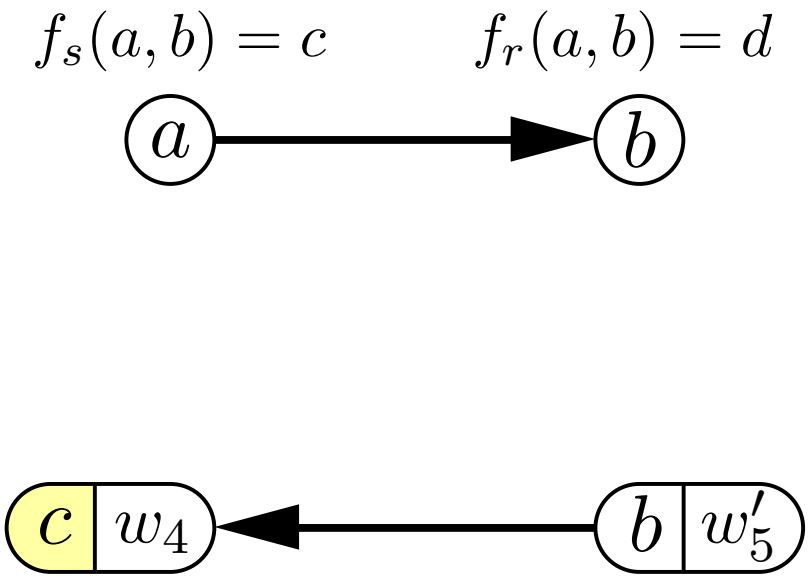

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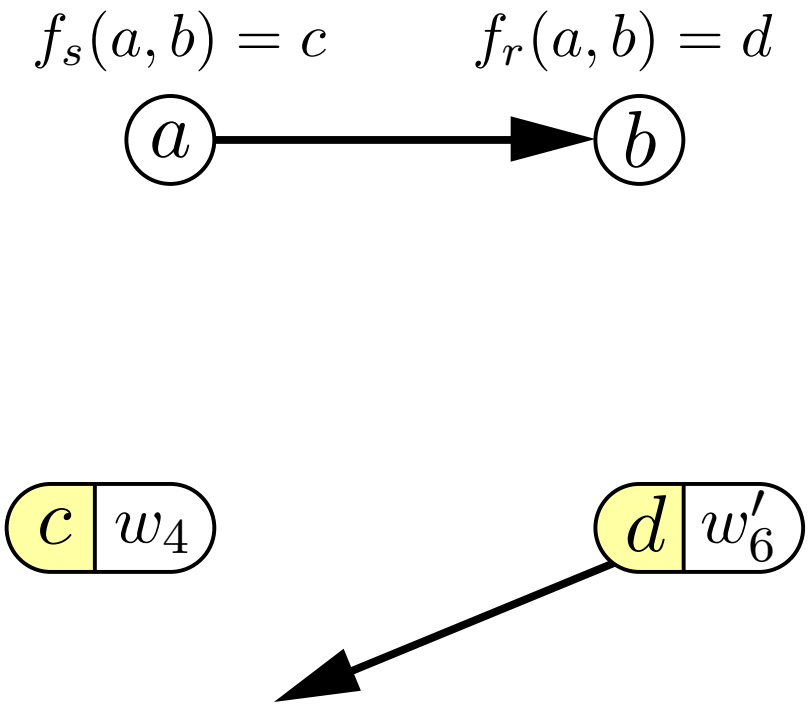
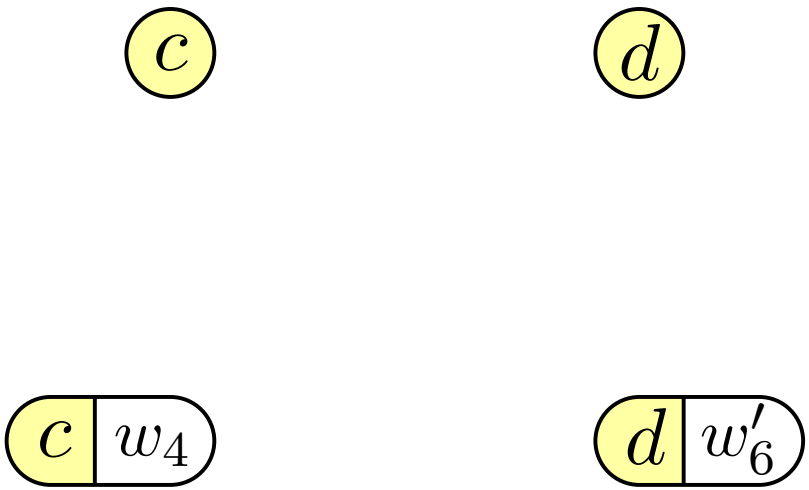
Simulating TW protocols with weaker ones



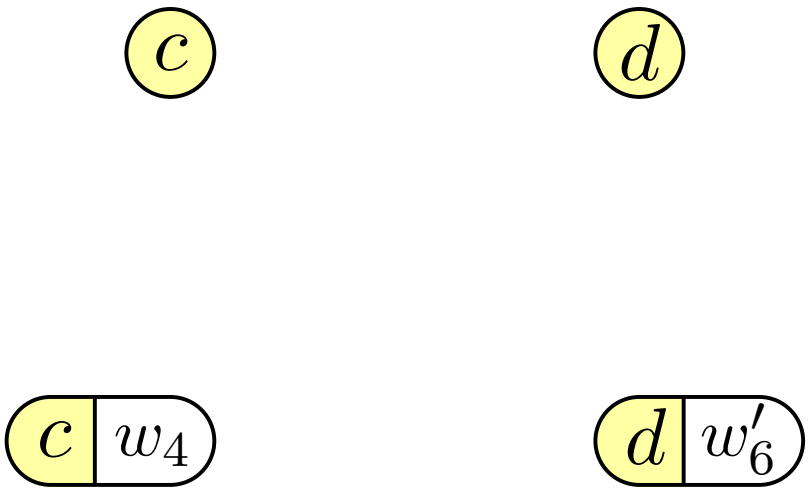
These have to mimic transitions in the simulated TW protocol.

Simulating TW protocols with weaker ones



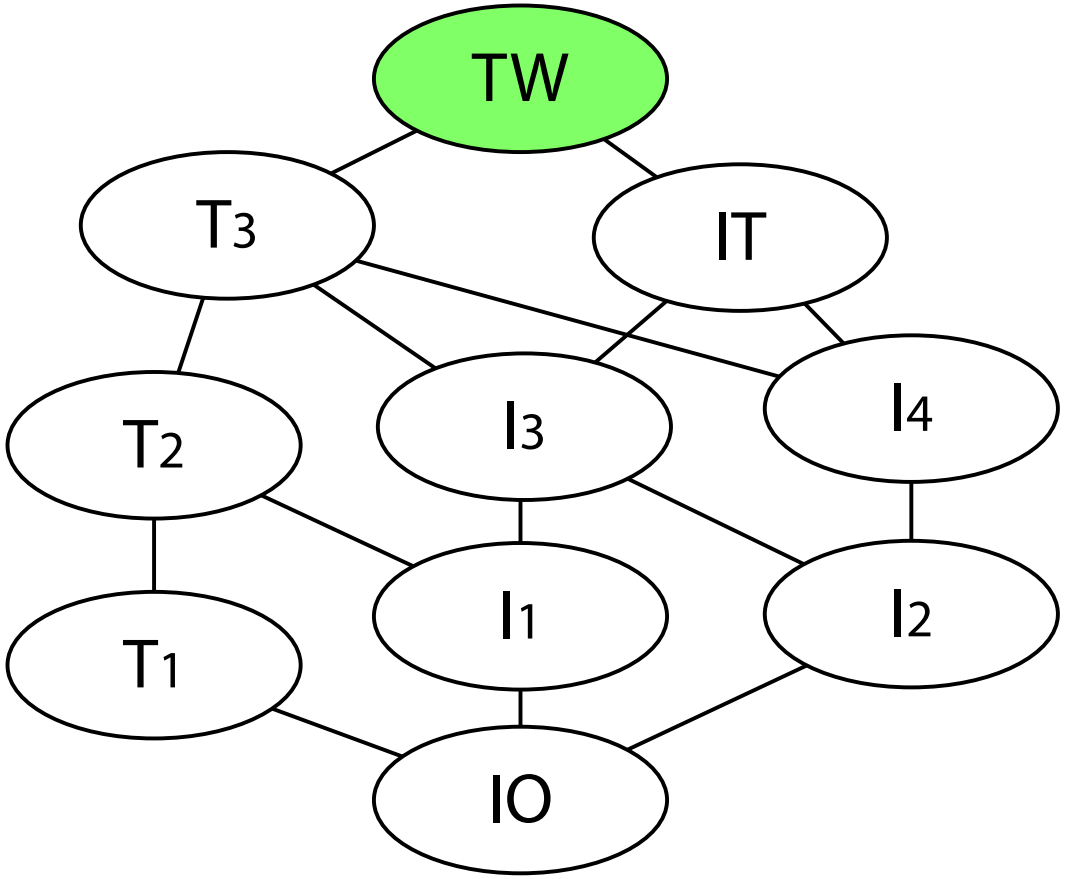
Globally, we want to pair up simulated states transitions...

Simulating TW protocols with weaker ones



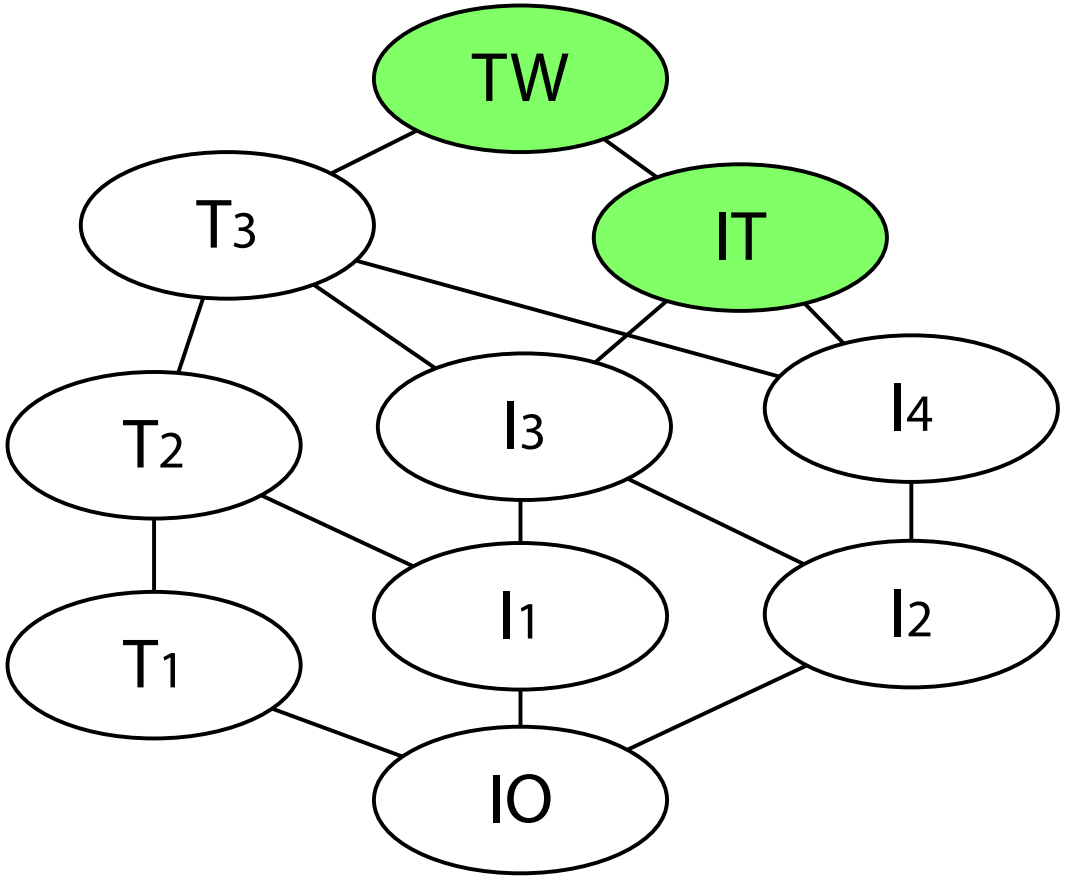
...in a way that is compatible with the simulated TW protocol.

Results: infinite memory



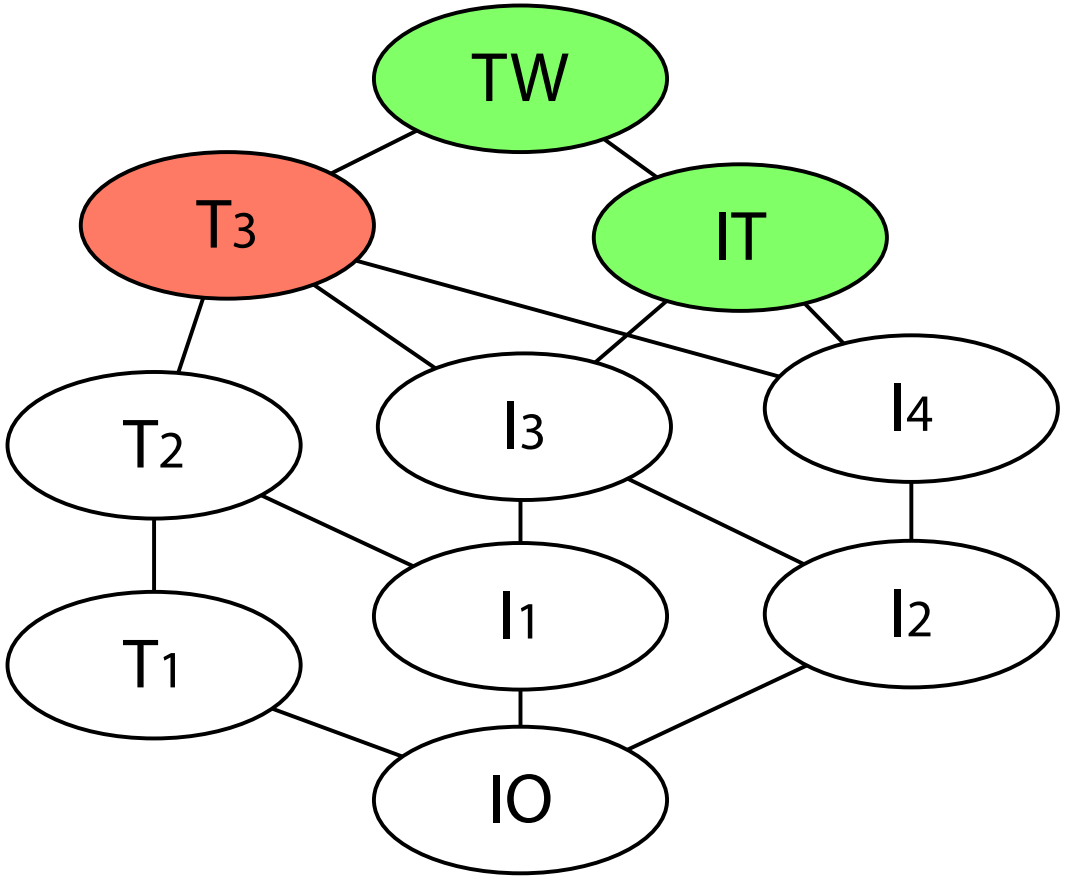
Suppose the simulating agents have **infinite memory**: what models can simulate *all* TW population protocols?

Results: infinite memory



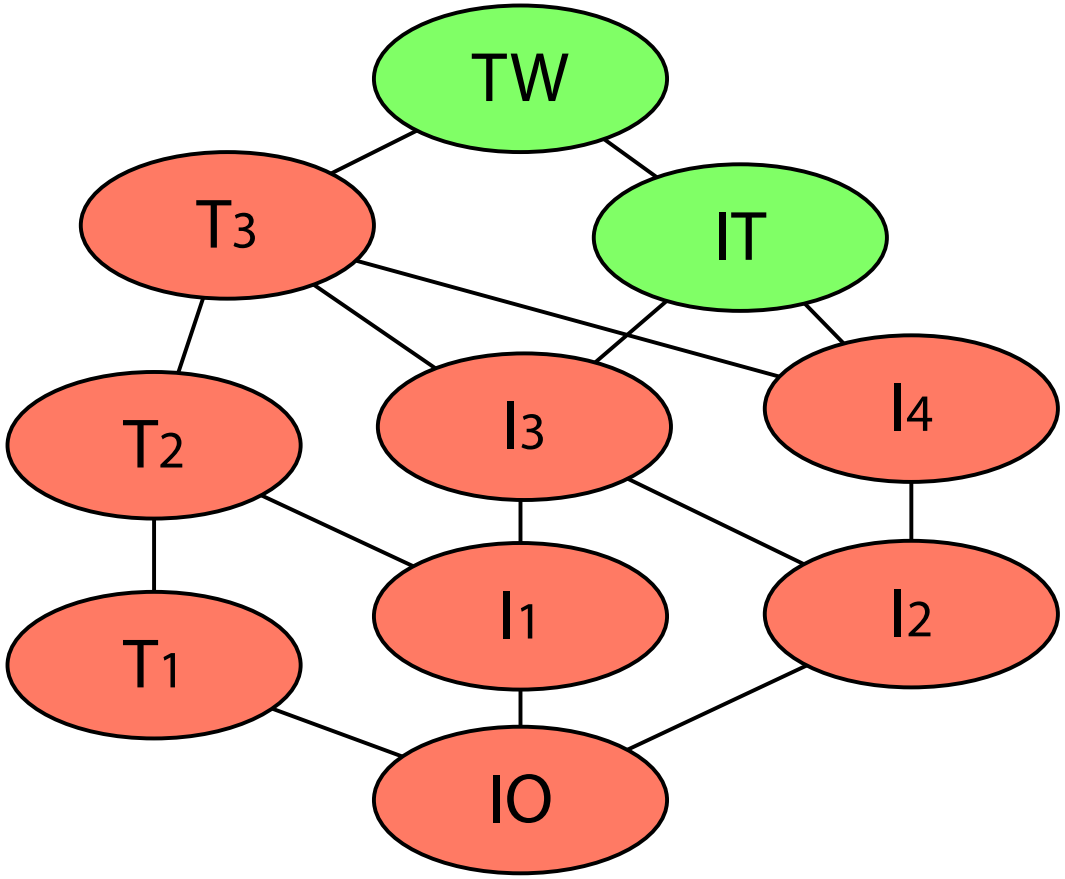
In **IT**, we can implement a *token-passing* technique that can be used to simulate two-way interactions.

Results: infinite memory



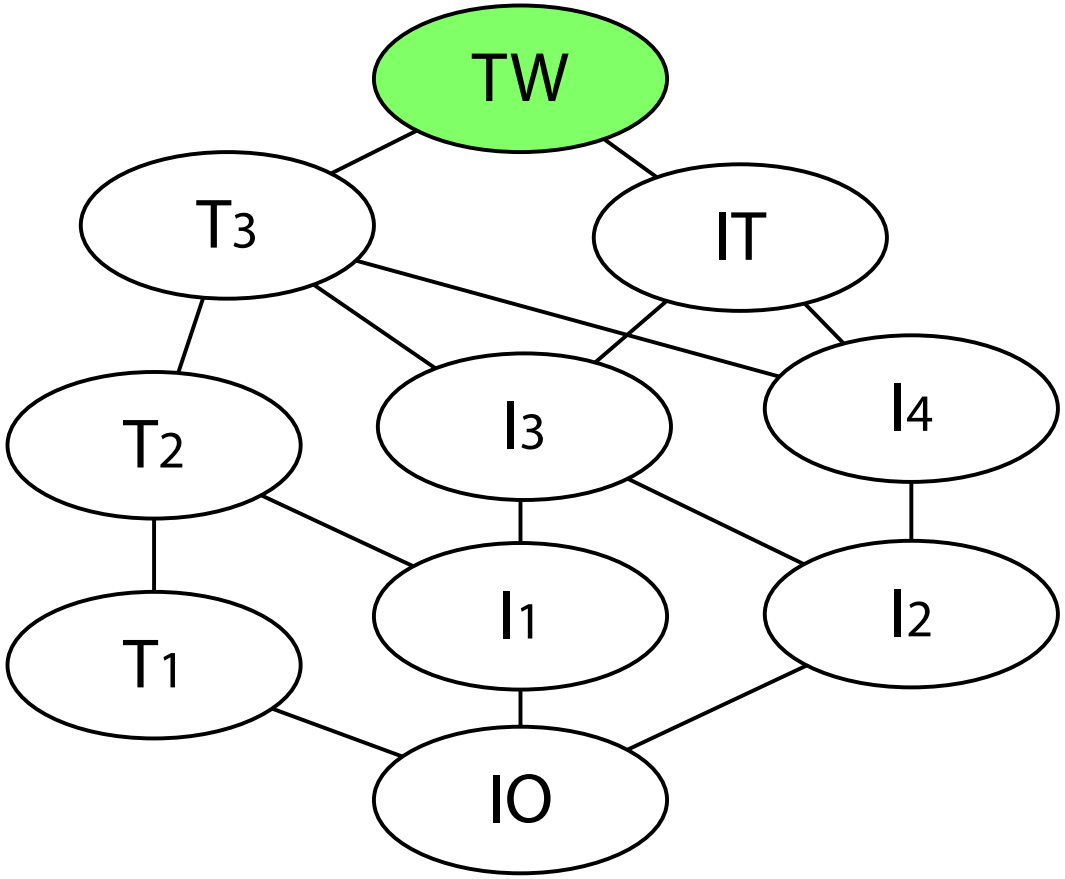
In $\mathbf{T_3}$, it is impossible to simulate a two-way protocol for the *pairing problem*.

Results: infinite memory



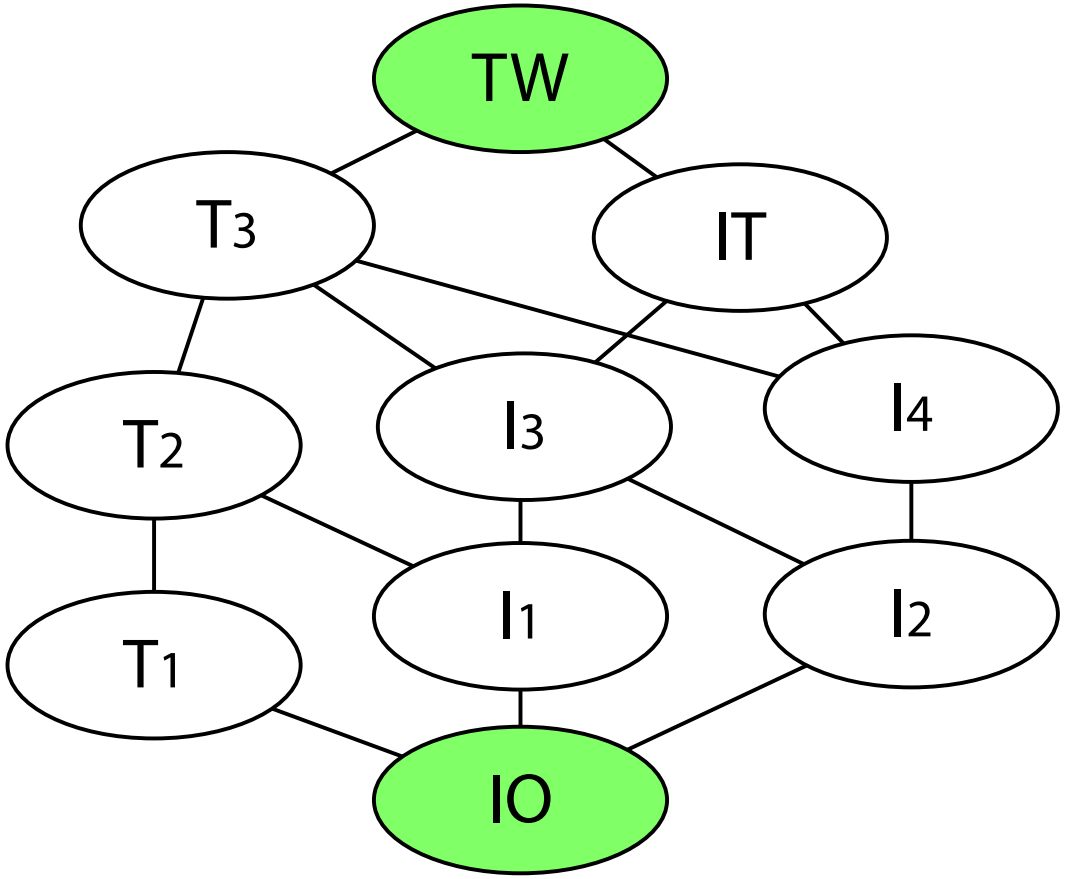
As a consequence, simulation is impossible also in the weaker interaction models.

Results: unique IDs



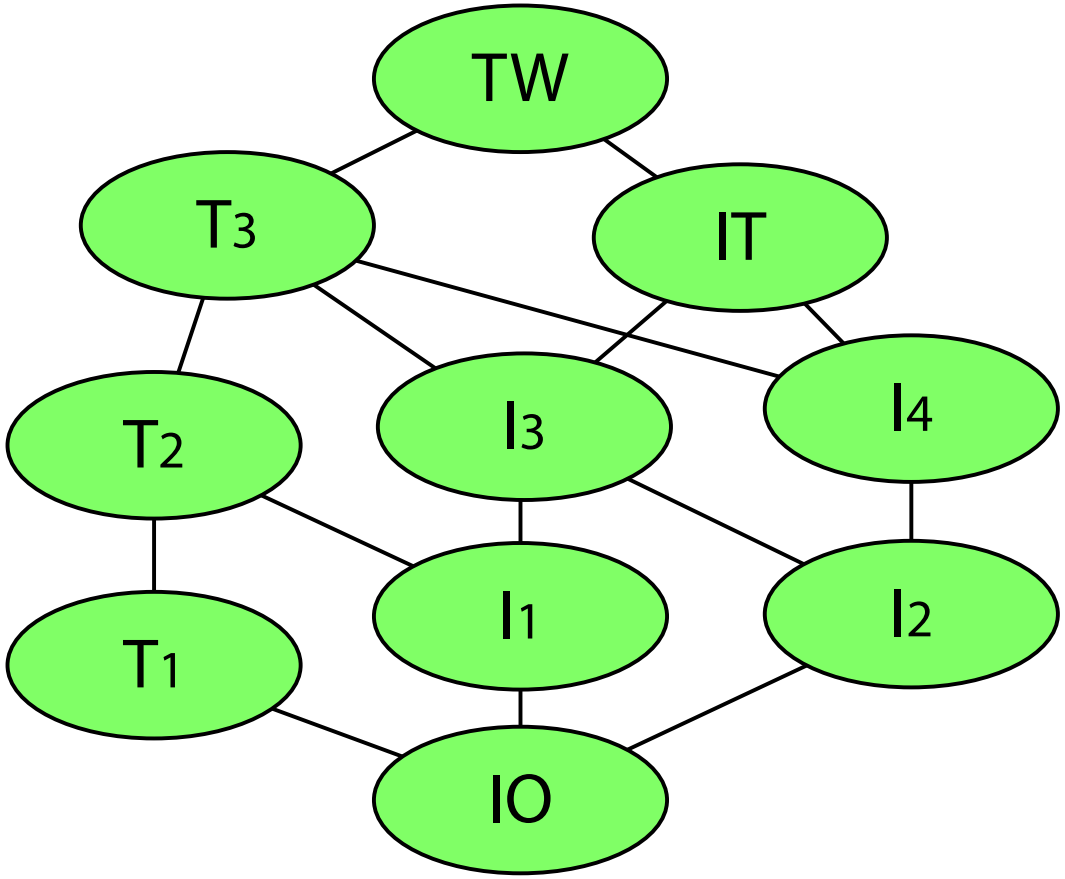
Suppose the simulating agents have *unique IDs* as part of their initial state.

Results: unique IDs



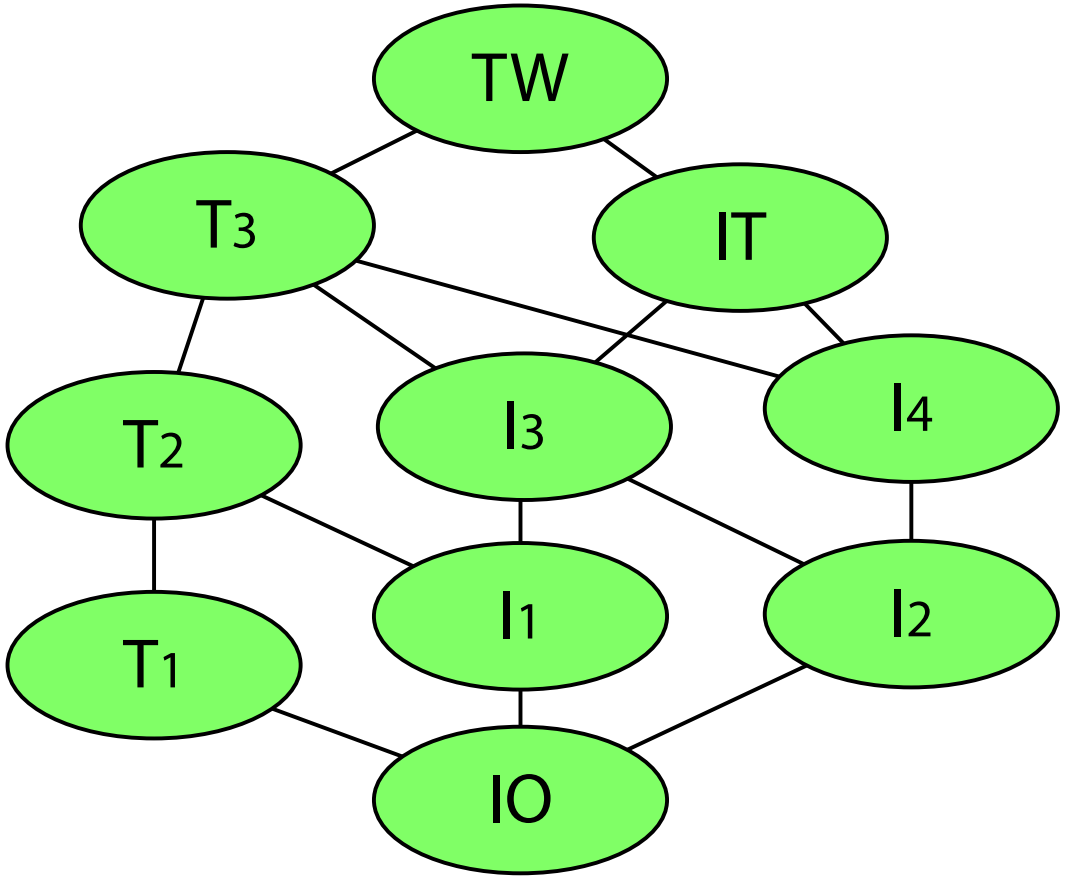
In **IO**, we can implement a *locking mechanism*, along with a *rollback process* to avoid deadlocks.

Results: unique IDs



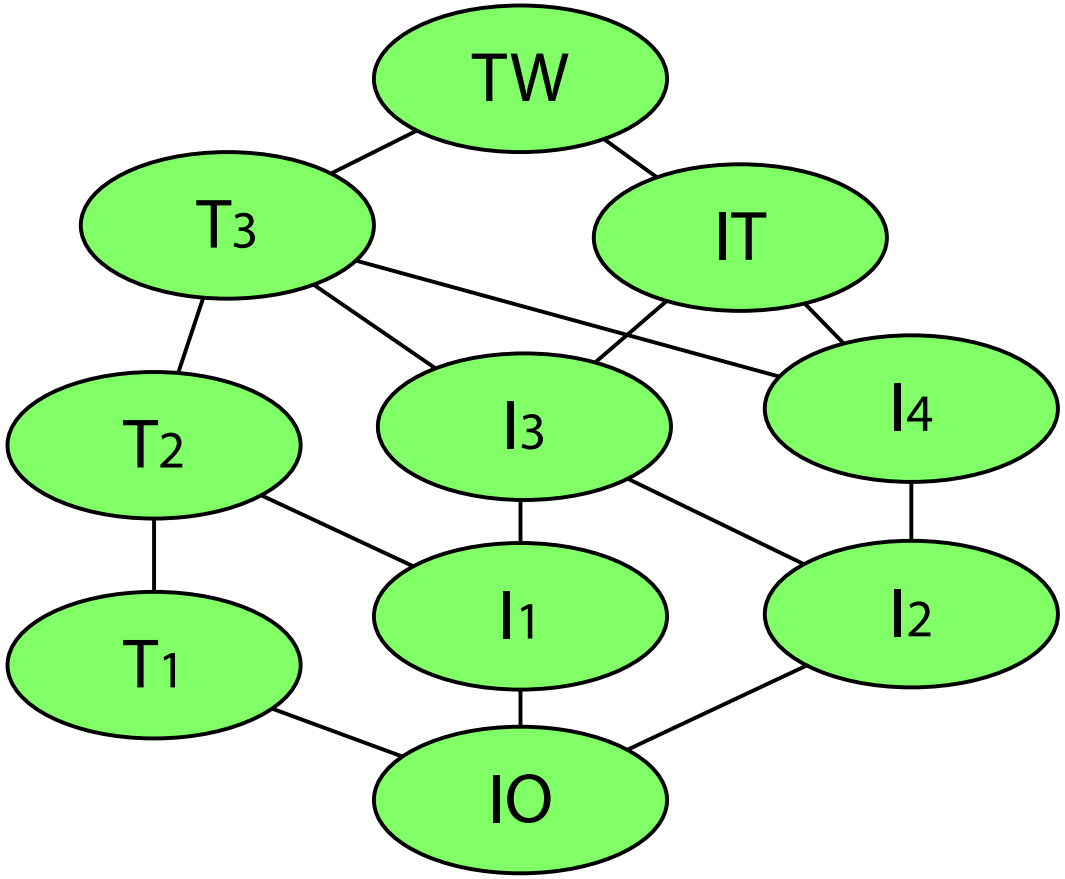
As a consequence, simulation is possible also in the stronger interaction models.

Results: knowledge of n



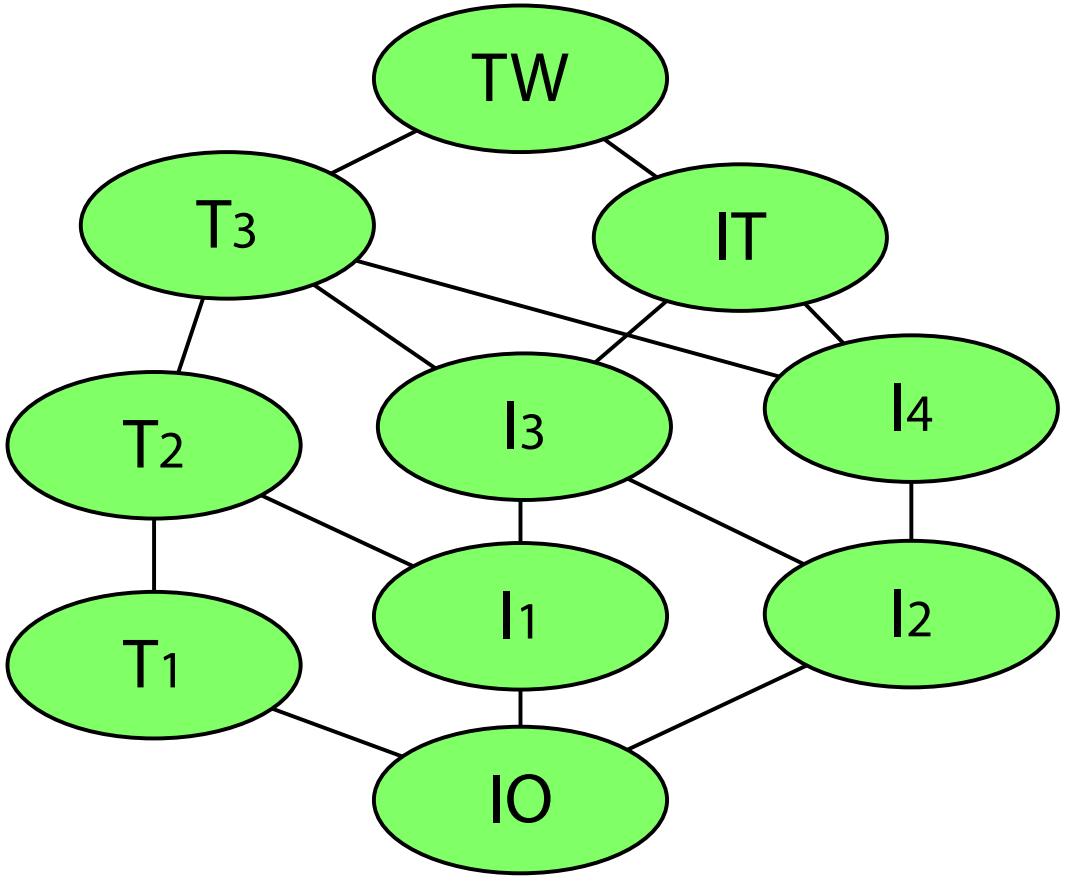
Suppose the simulating agents know the size of the system, n, and have $O(\log n)$ bits of internal memory.

Results: knowledge of n



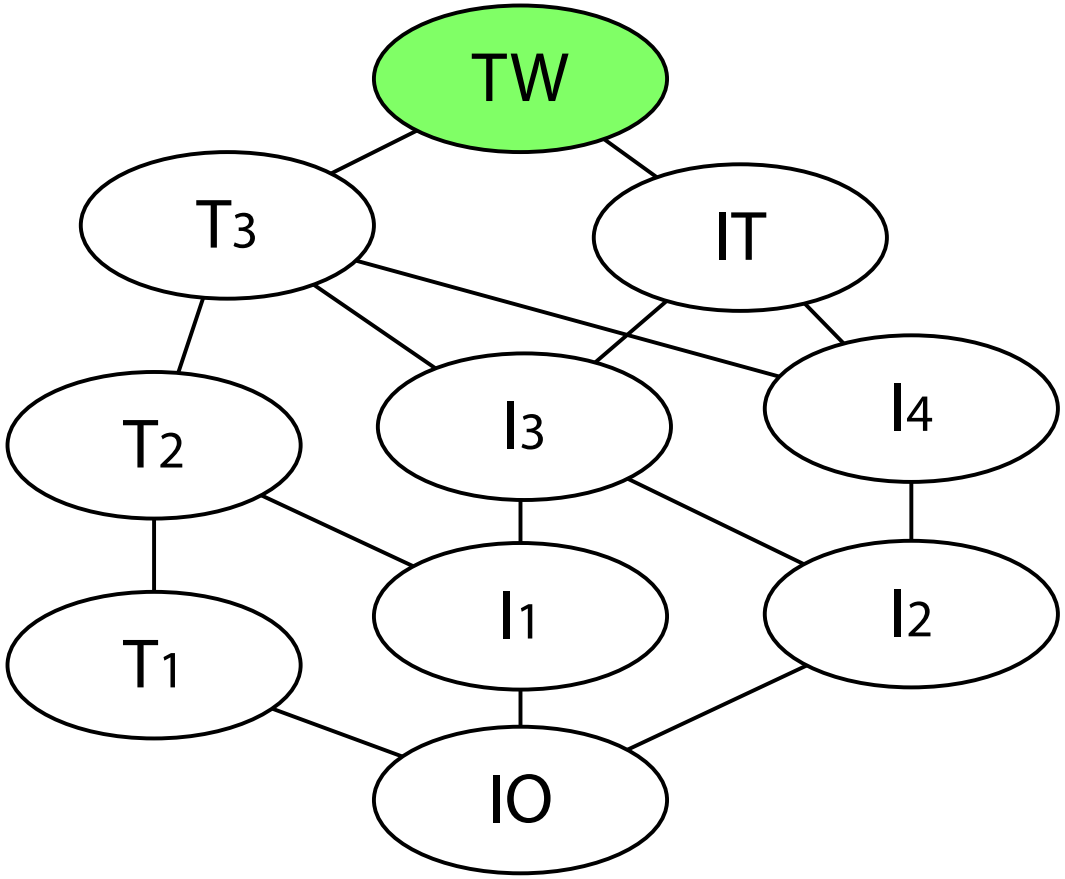
In **IO**, we can implement a *naming algorithm* that eventually gives each agent a unique ID.

Results: knowledge of n



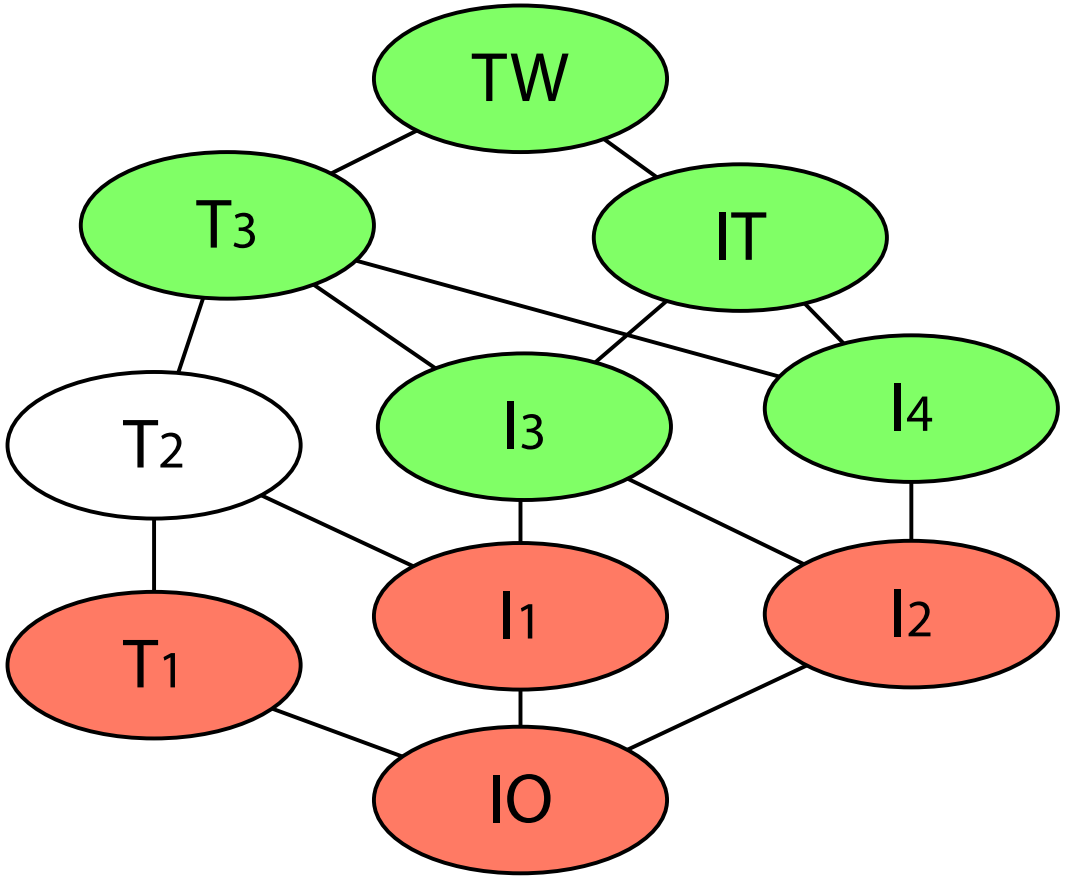
When an agent has ID n, the system starts executing the previous unique-ID simulation protocol.

Results: knowledge on omissions



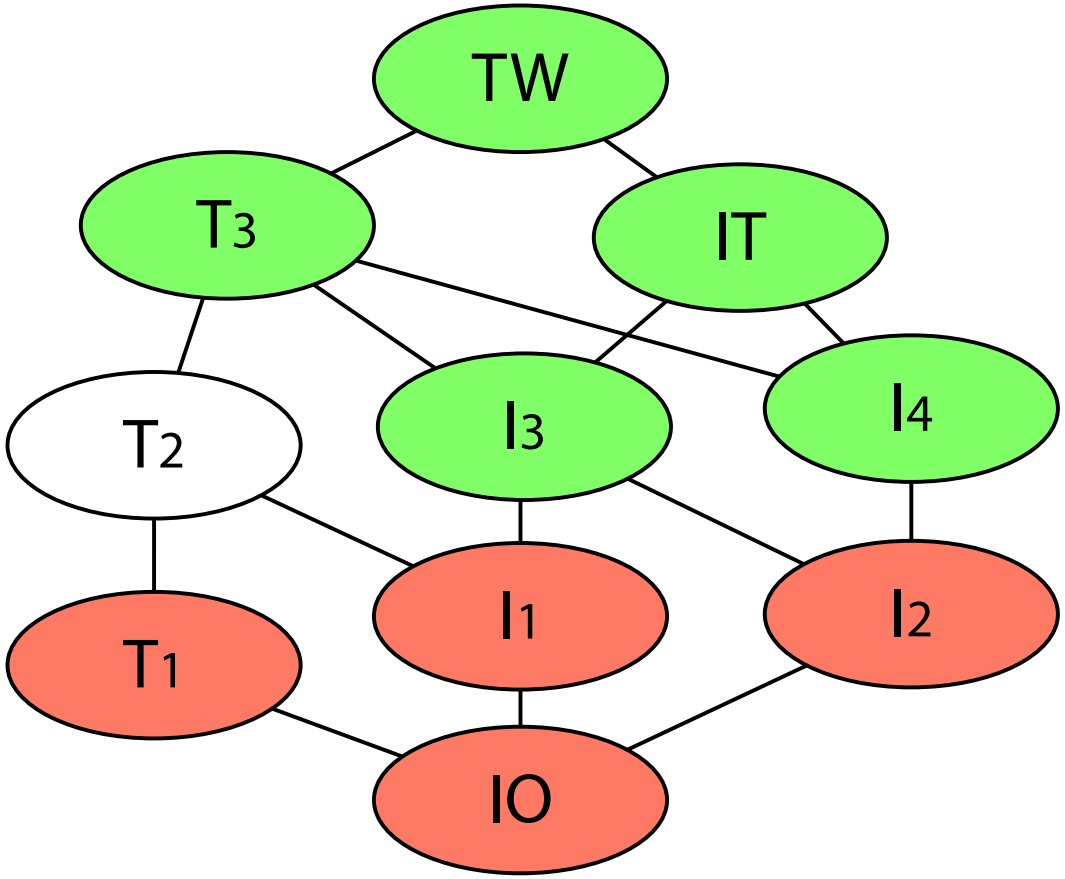
Suppose that the simulating agents are given an upper bound b on the number of faulty interactions in the system.

Results: knowledge on omissions



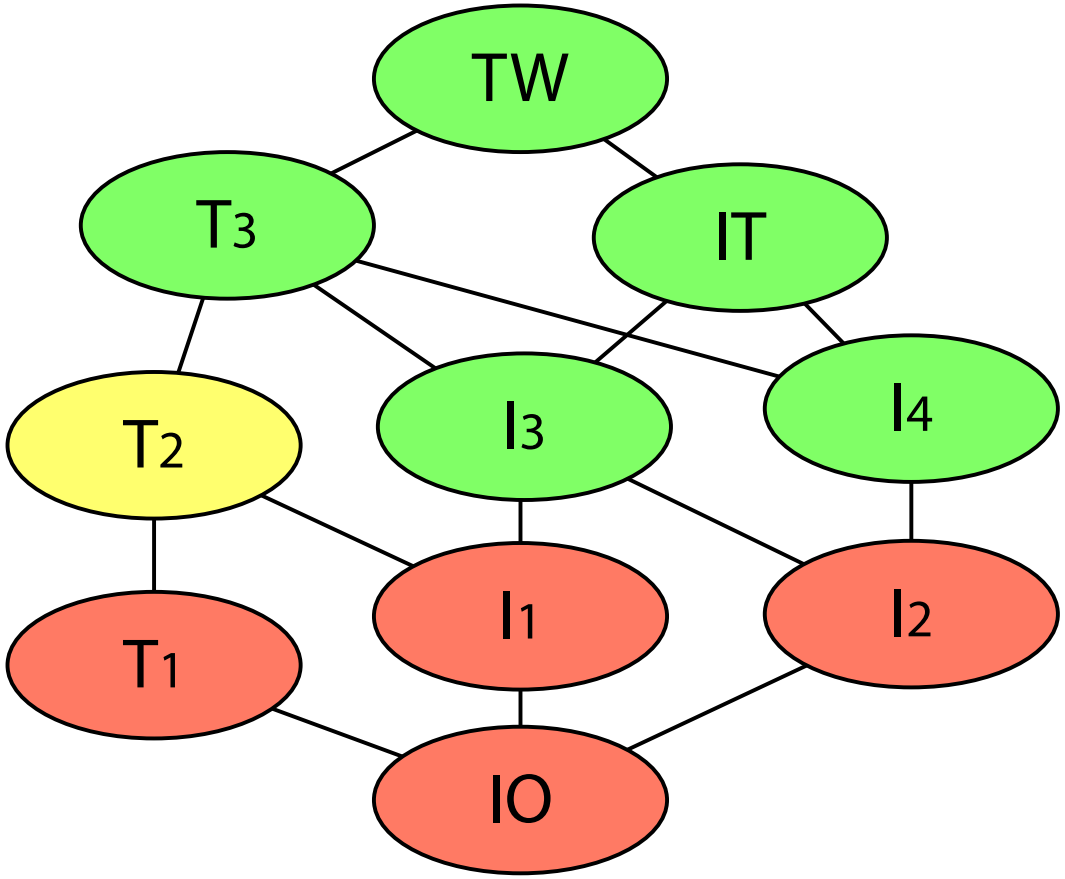
In $\mathbf{I_3}$ and $\mathbf{I_4}$, we can extend the token-passing technique by splitting each token into $b + 1$ parts.

Results: knowledge on omissions



In $\mathbf{T_1}$, $\mathbf{I_1}$, and $\mathbf{I_2}$, it is impossible to simulate the pairing protocol, even for $b = 1$.

Results: knowledge on omissions



Open problem: is it possible to simulate all TW protocols in $\mathbf{T_2}$, given an upper bound on the number of faulty interactions?