Models and Theory of Computation (MTC)
EPFL

Dirk Beyer, Jasmin Fisher, Nir Piterman

Simon Kramer: Logic for cryptography
Marc Schaub: Models for biological systems
Vasu Singh: Software interface derivation
Gregory Theoduloz: Combining model checking and program analysis

Arindam Chakrabarti: Web service interfaces
Krishnendu Chatterjee: Stochastic games
Slobodan Matic: Time-triggered programming
Vinayak Prabhu: Robust hybrid systems

Model Checking:
From Graphs to Games

Tom Henzinger
EPFL

Graph Models of Systems

vertices = states

edges = transitions

paths = behaviors

Game Models of Systems

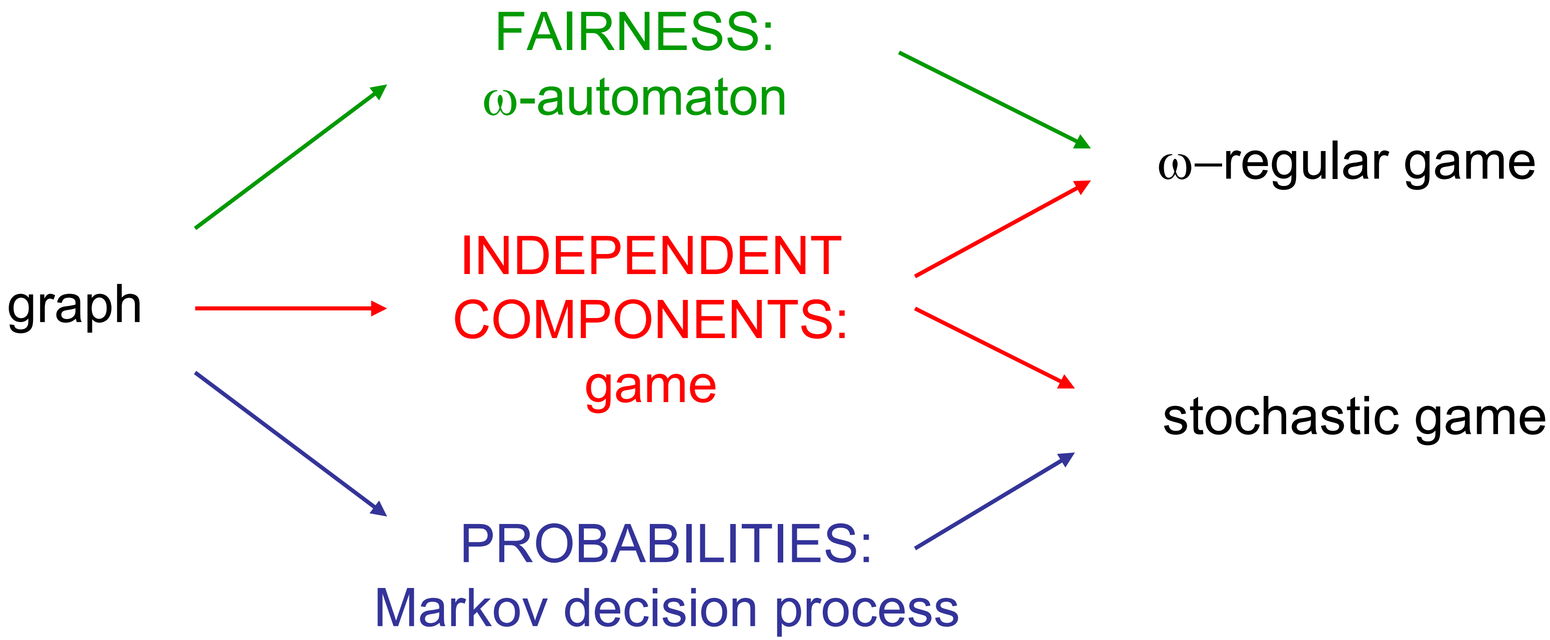
vertices = states

edges = transitions

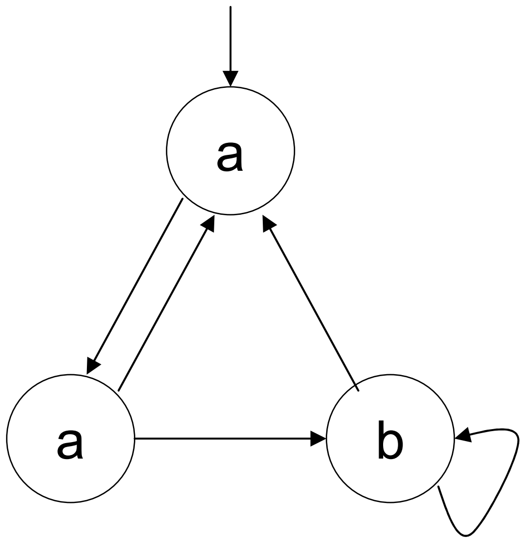
paths = behaviors

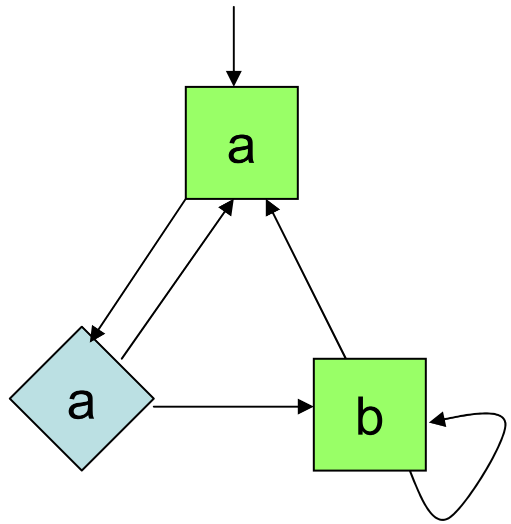
players = components

Game Models of Systems



Graphs vs. Games





Game Models enable

-synthesis [Church, Rabin, Ramadge/Wonham, Pnueli/Rosner et al.]

-receptiveness [Dill, Abadi/Lamport]

-semantics of interaction [Abramsky]

-reasoning about adversarial behavior

-interface-based design

-modular reasoning [Kupferman/Vardi et al.]

-early error detection [deAlfaro/H/Mang]

-model-based testing [Gurevich et al.]

-scheduling [Sifakis et al.]

-reasoning about security [Raskin et al.]

-etc.

Game Models

Always about open systems:

-players = processes / components / agents

-input vs. output

-demonic vs. angelic nondeterminism

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1. Output games: input demonic (adversarial)
2. Input games: output demonic

Output Games

P1:

```
init  x := 0
loop
    choice
        |  x := x+1 mod 2
        |  x := 0
    end choice
end loop
```

P2:

```
init  y := 0
loop
    choice
        |  y := x
        |  y := x+1 mod 2
    end choice
end loop
```

S1: $\Box\,(x \geq y)$

S2: $\Box$ even(y)

Graph Questions

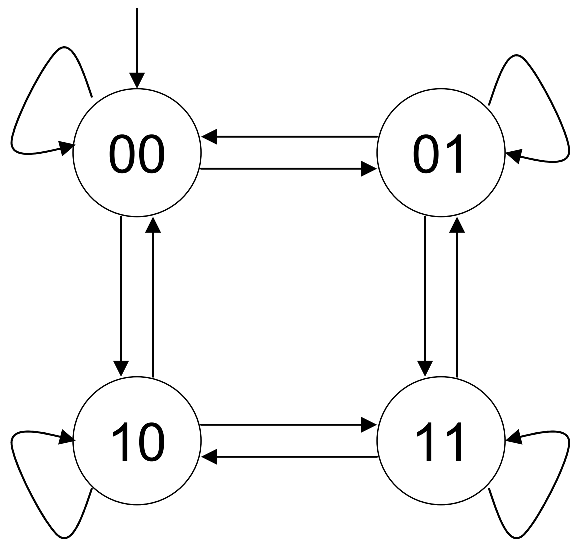
$\forall \Box (x \geq y)$

$\exists \Box (x \geq y)$

Graph Questions

✗ $\forall \Box (x \geq y)$

✓ $\exists \Box (x \geq y)$



Zero-Sum Game Questions

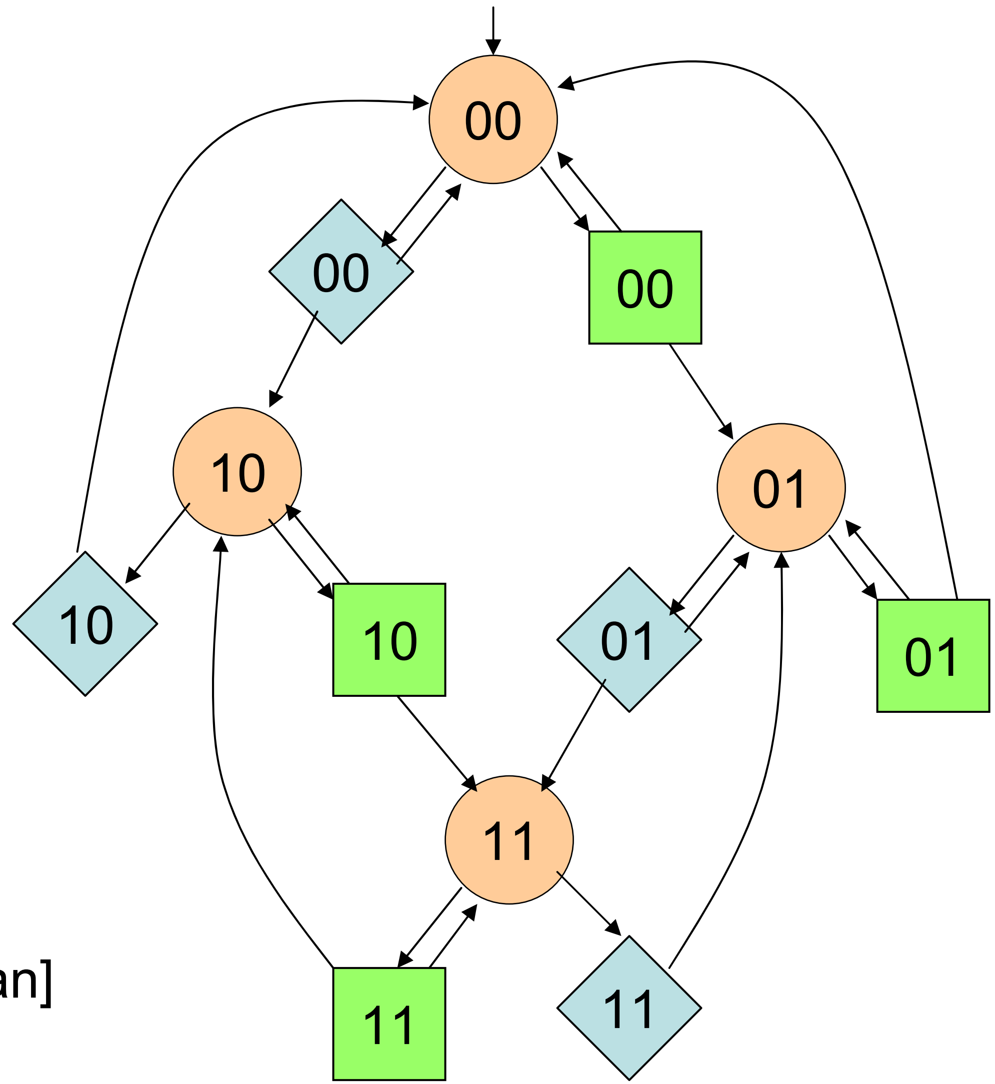
$\langle\langle P1 \rangle\rangle \,\square\, (x \geq y)$

$\langle\langle P2 \rangle\rangle \,\square\, \text{even}(y)$

Zero-Sum Game Questions

✗ $\langle\langle P1 \rangle\rangle \, \Box \, (x \geq y)$

✓ $\langle\langle P2 \rangle\rangle \, \Box \, even(y)$



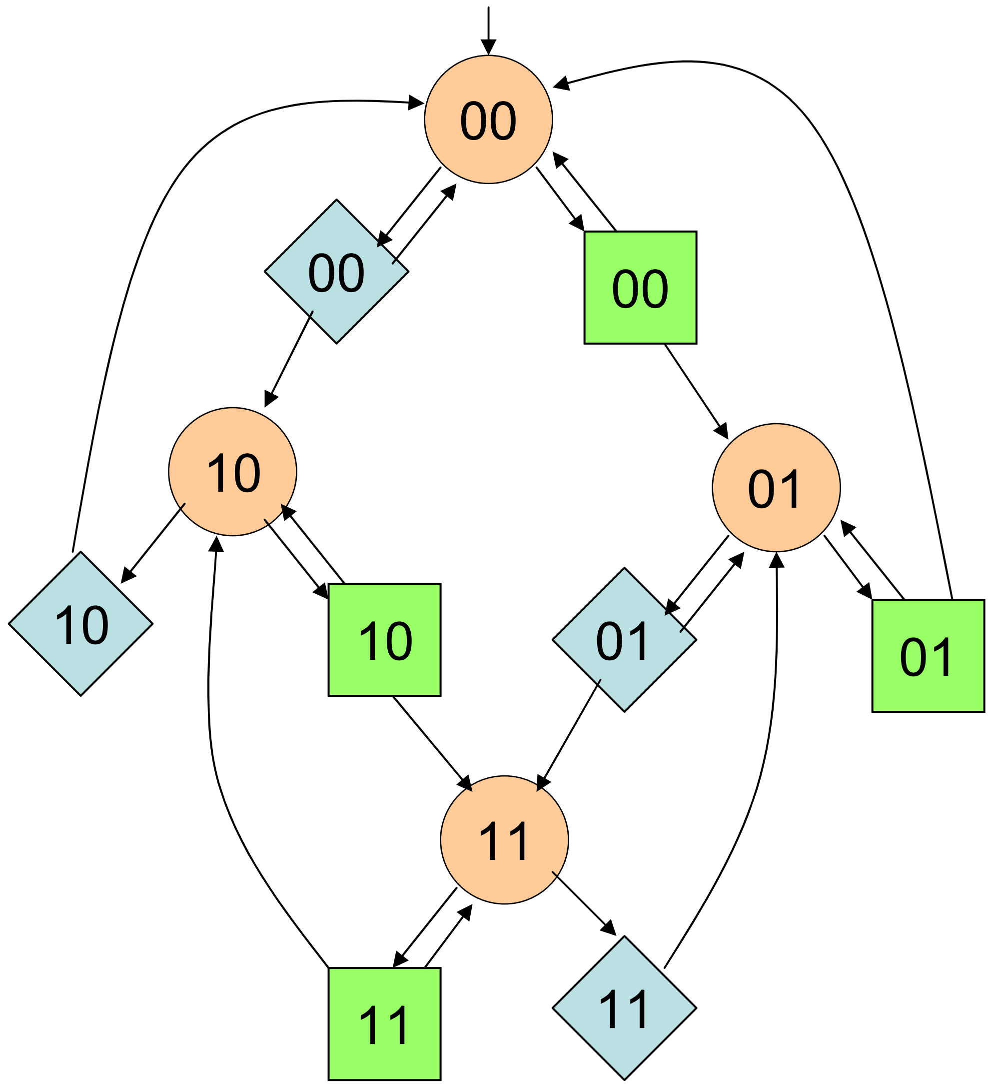
ATL [Alur/H/Kupferman]

Nonzero-Sum Game Questions

$\langle\langle P1 \rangle\rangle \; \Box \; (x \geq y)$

$\otimes$

$\langle\langle P2 \rangle\rangle \; \Box \; \mathrm{even}(y)$



Nonzero-Sum Game Questions

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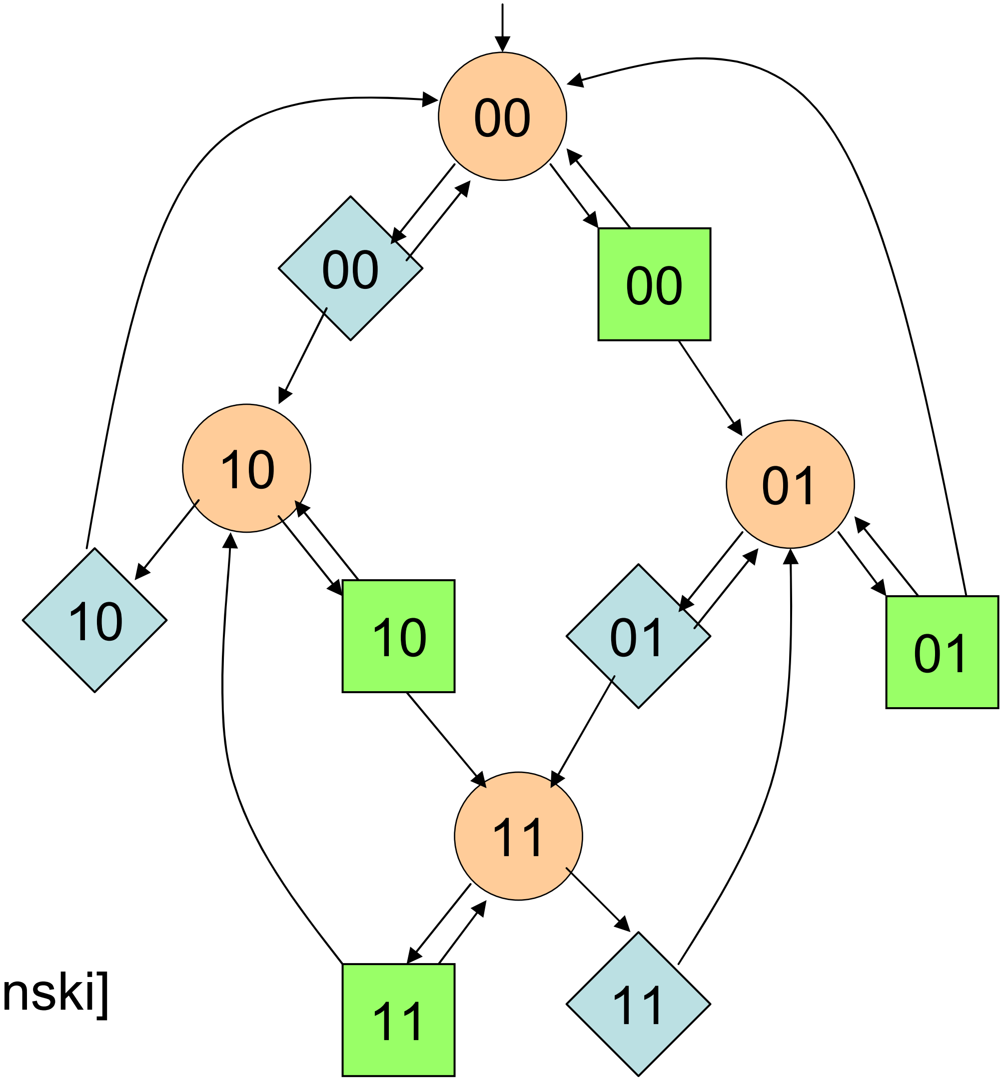


Secure equilibrium
[Chatterjee/H/Jurdzinski]

Classical Notion of Rationality

Nash equilibrium: none of the players gains by deviation.

(row, column)

3,1	1,0
3,2	4,2

Refined Notion of Rationality

Nash equilibrium: none of the players gains by deviation.

Secure equilibrium: none hurts the opponent by deviation.

(row, column)

3,1	1,0
3,2	4,2

Secure Equilibrium

- Natural notion of rationality for multi-component systems:
  - First, a component tries to meet its specification.
  - Second, a component may obstruct the other components.
- A secure equilibrium is a contract:

  if one player deviates to lower the other player's payoff,
  then her own payoff decreases as well, and vice versa.

Theorem

$\mathbf{W_{01}}$
$\langle\langle P2 \rangle\rangle\,(S2 \wedge \neg\, S1)$

$\mathbf{W_{00}}$

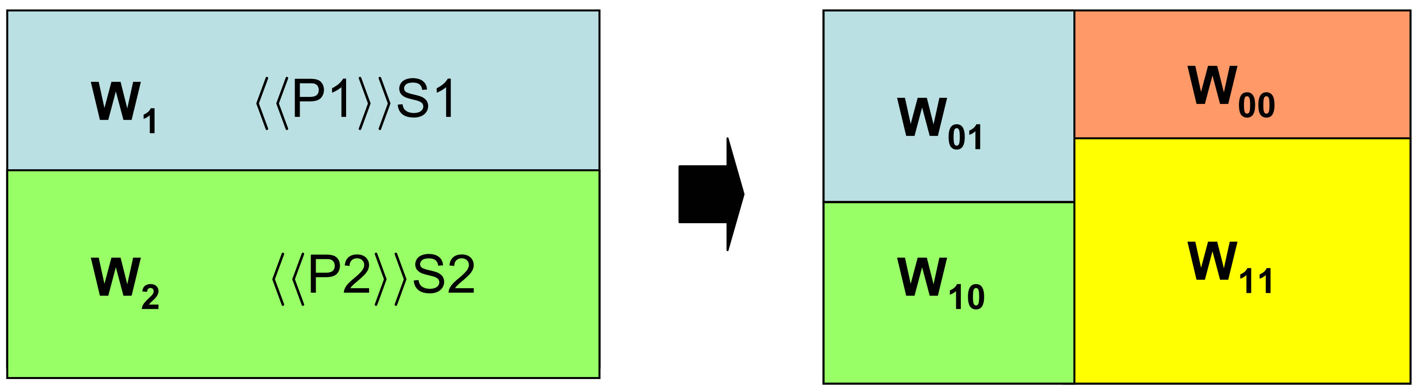
$\mathbf{W_{10}}$
$\langle\langle P1 \rangle\rangle\,(S1 \wedge \neg\, S2)$

$\mathbf{W_{11}}$
$\langle\langle P1 \rangle\rangle S1 \otimes \langle\langle P2 \rangle\rangle S2$

Generalization of Determinacy

Zero-sum games: S1 = ¬S2

Nonzero-sum games: S1, S2



Game Models

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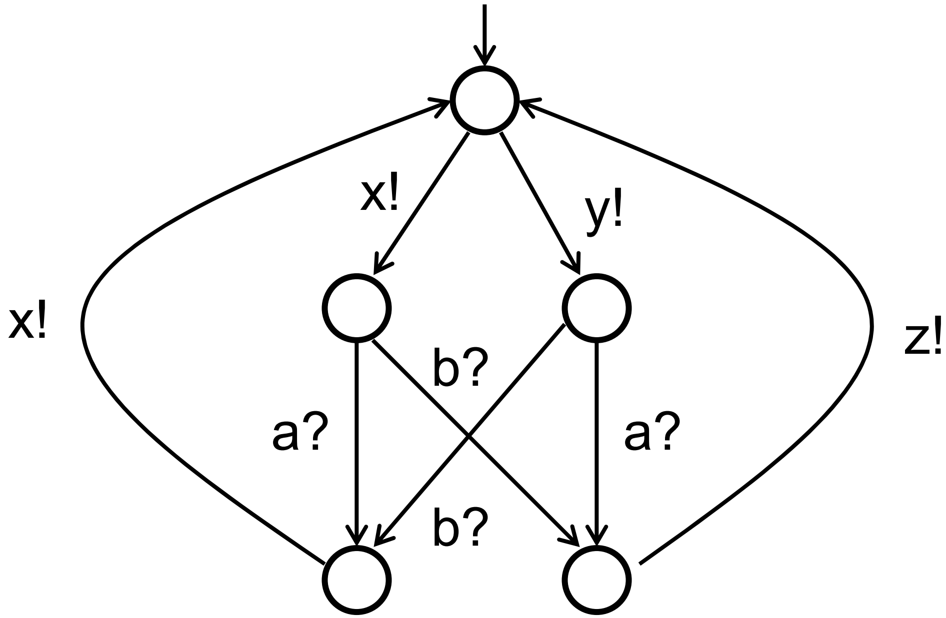
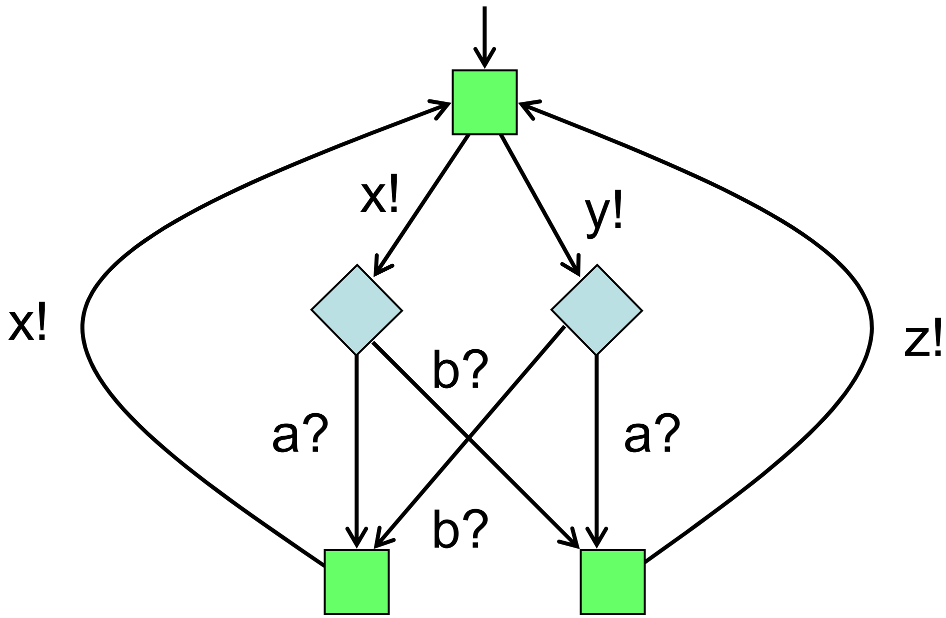
Input Games



Control objective:
□ ¬ z

Input Games



Control objective:
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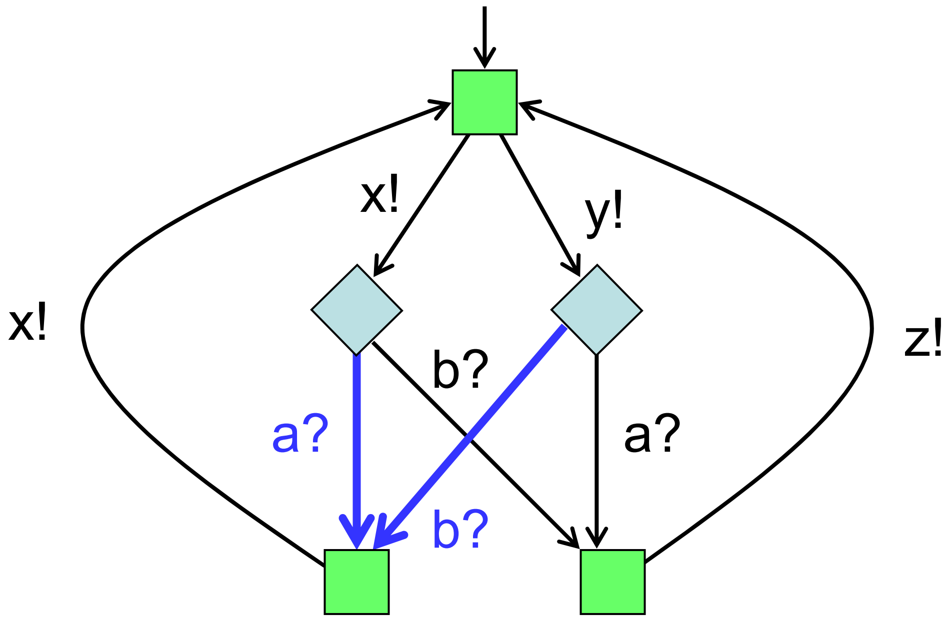
Input Games



Control objective:
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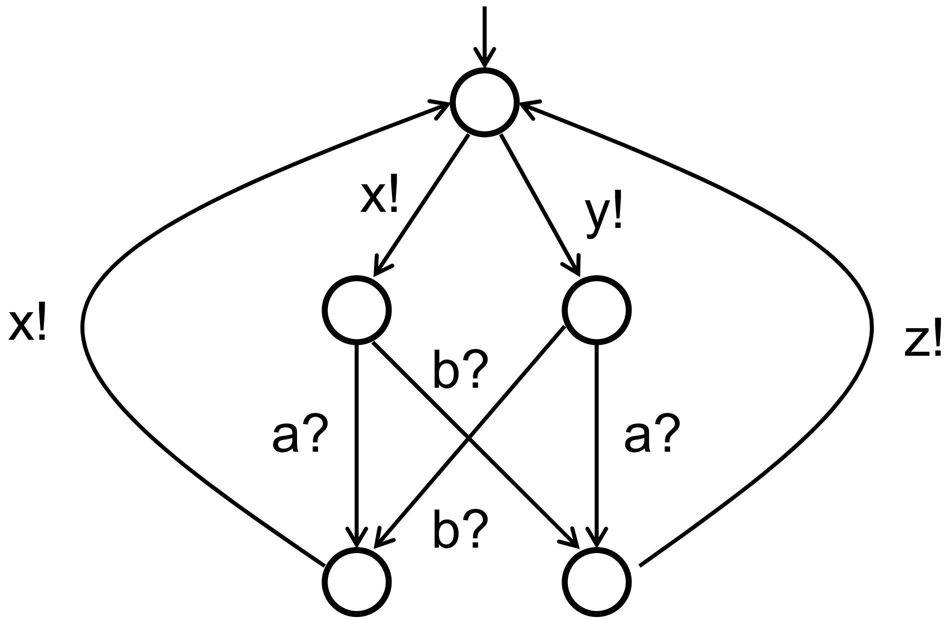
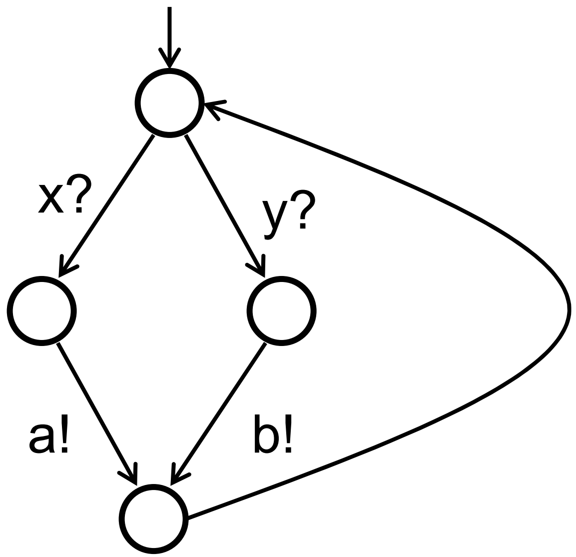
Input Games

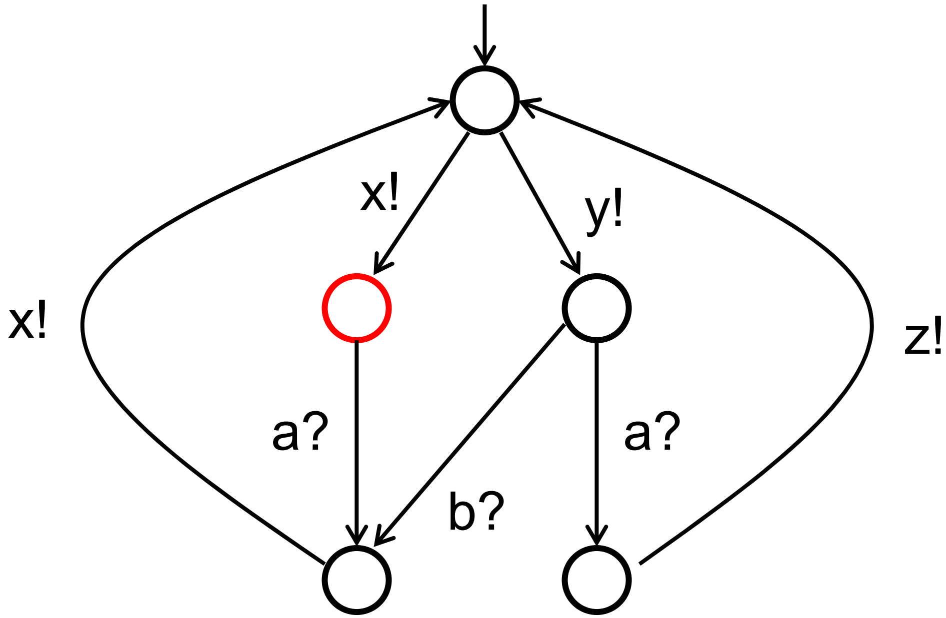


Controller:



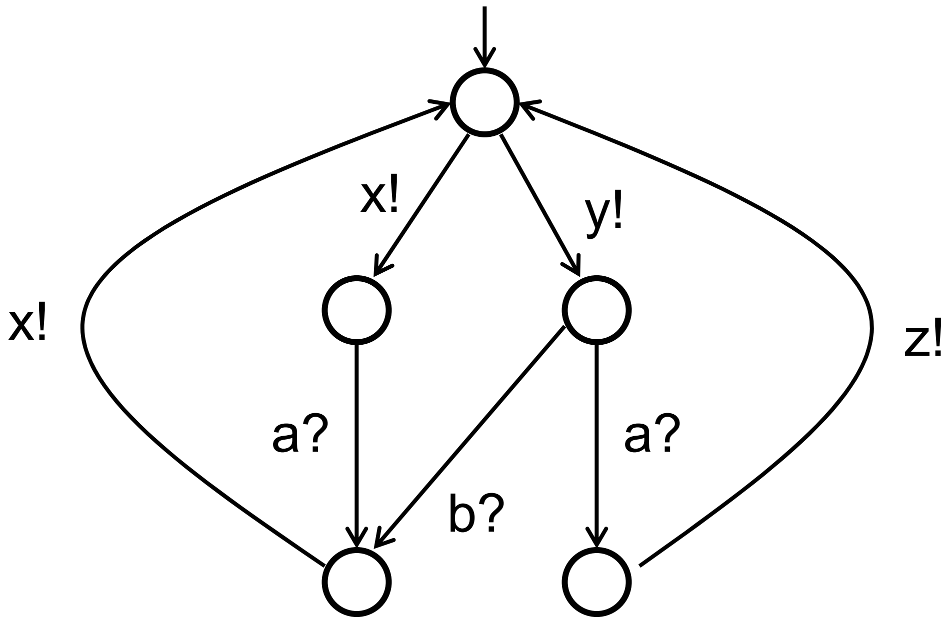
[Ramadge/Wonham et al.]

Input Games



Not input enabling

Input Games



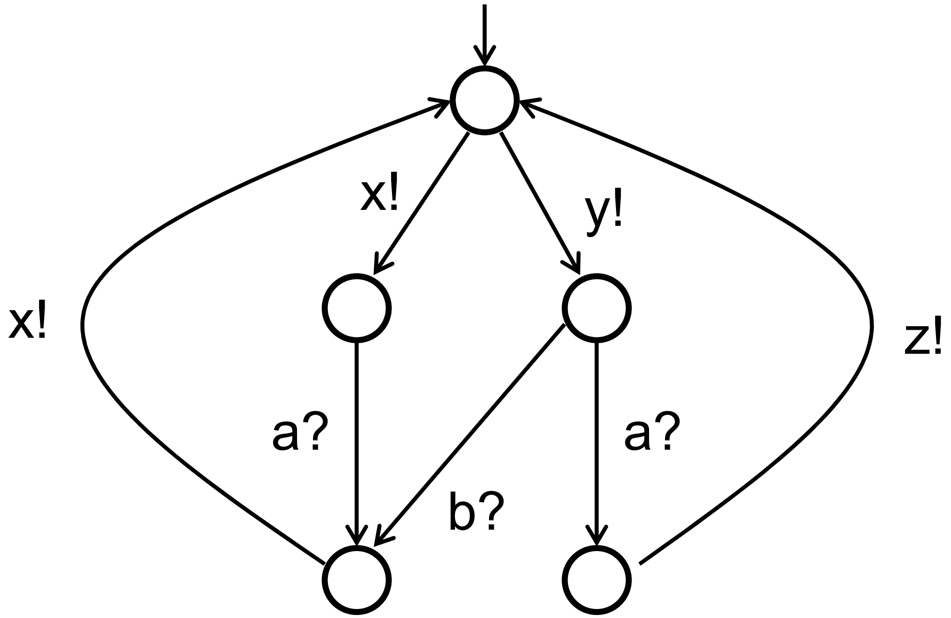
Environment avoids deadlock

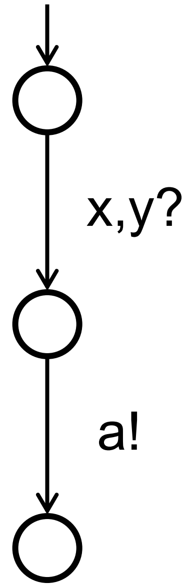
=

Input assumption

Interface automata [deAlfaro/H]

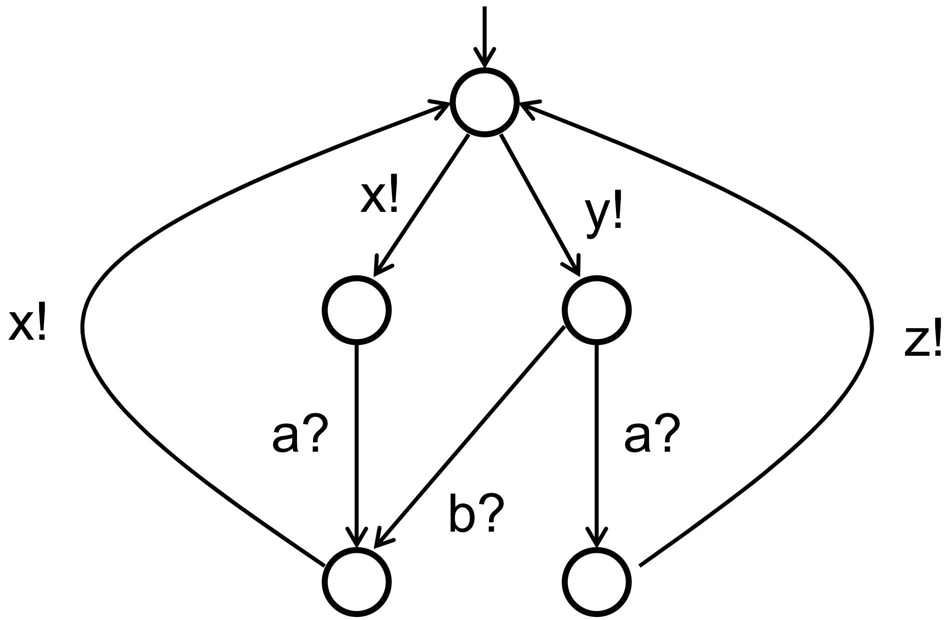
Input Games

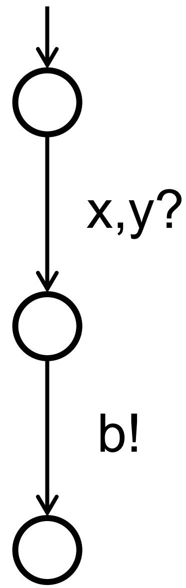




Legal environment

Input Games

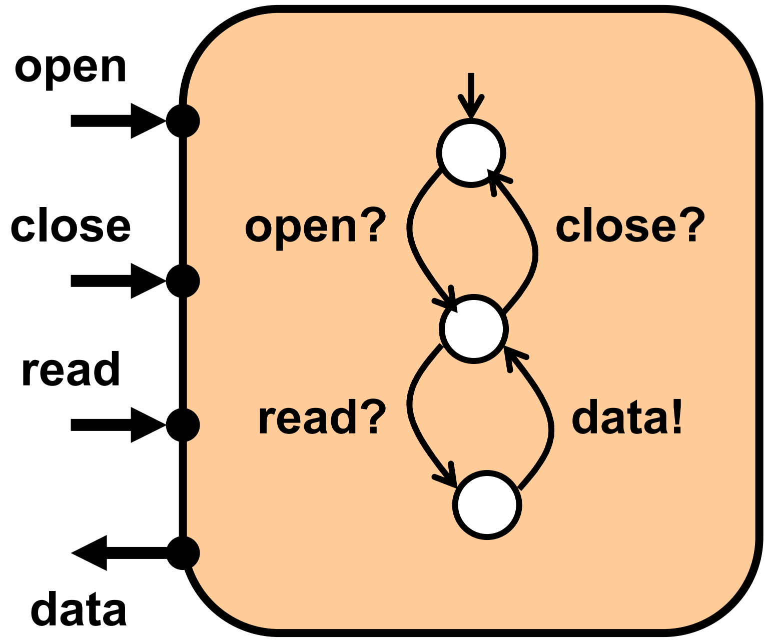




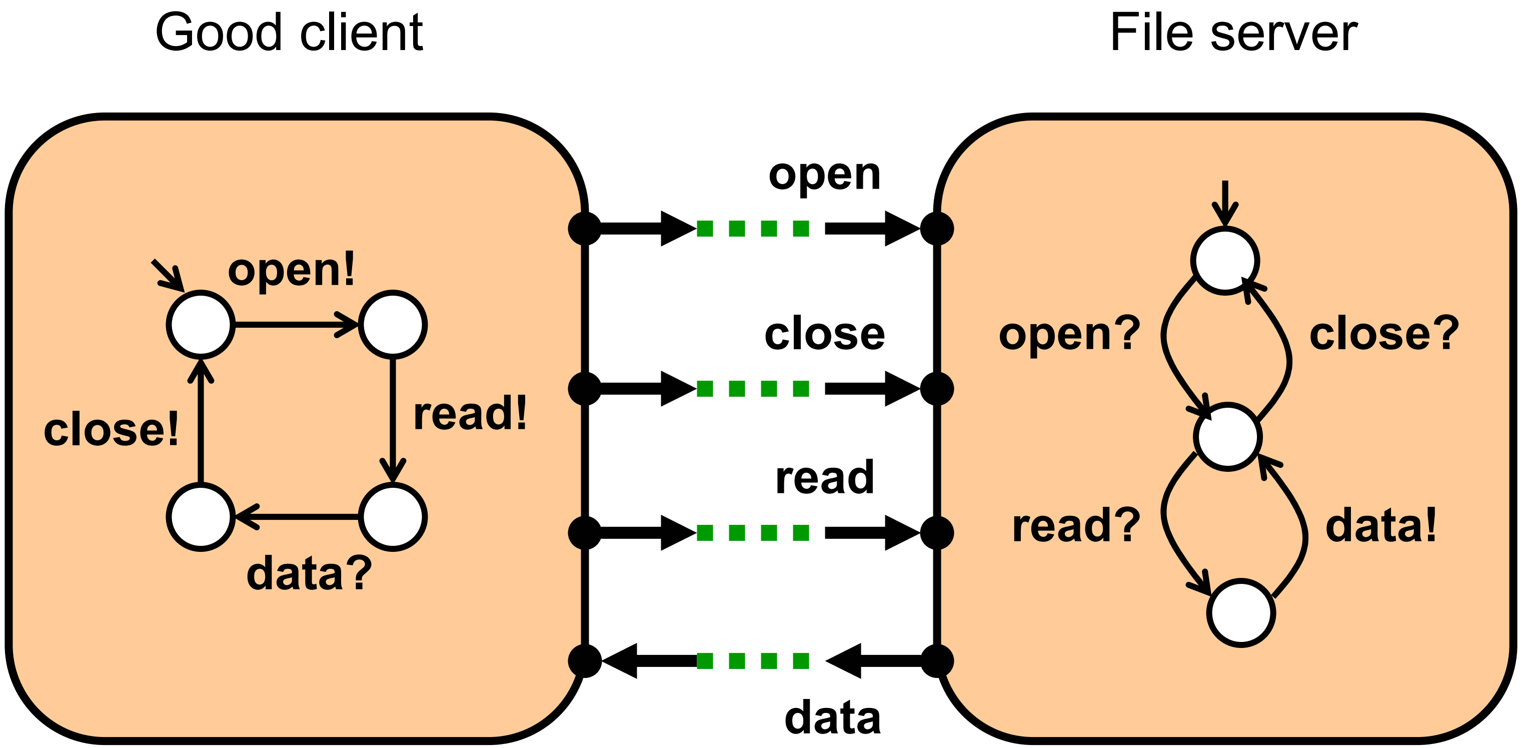
Illegal environment

Interface Compatibility

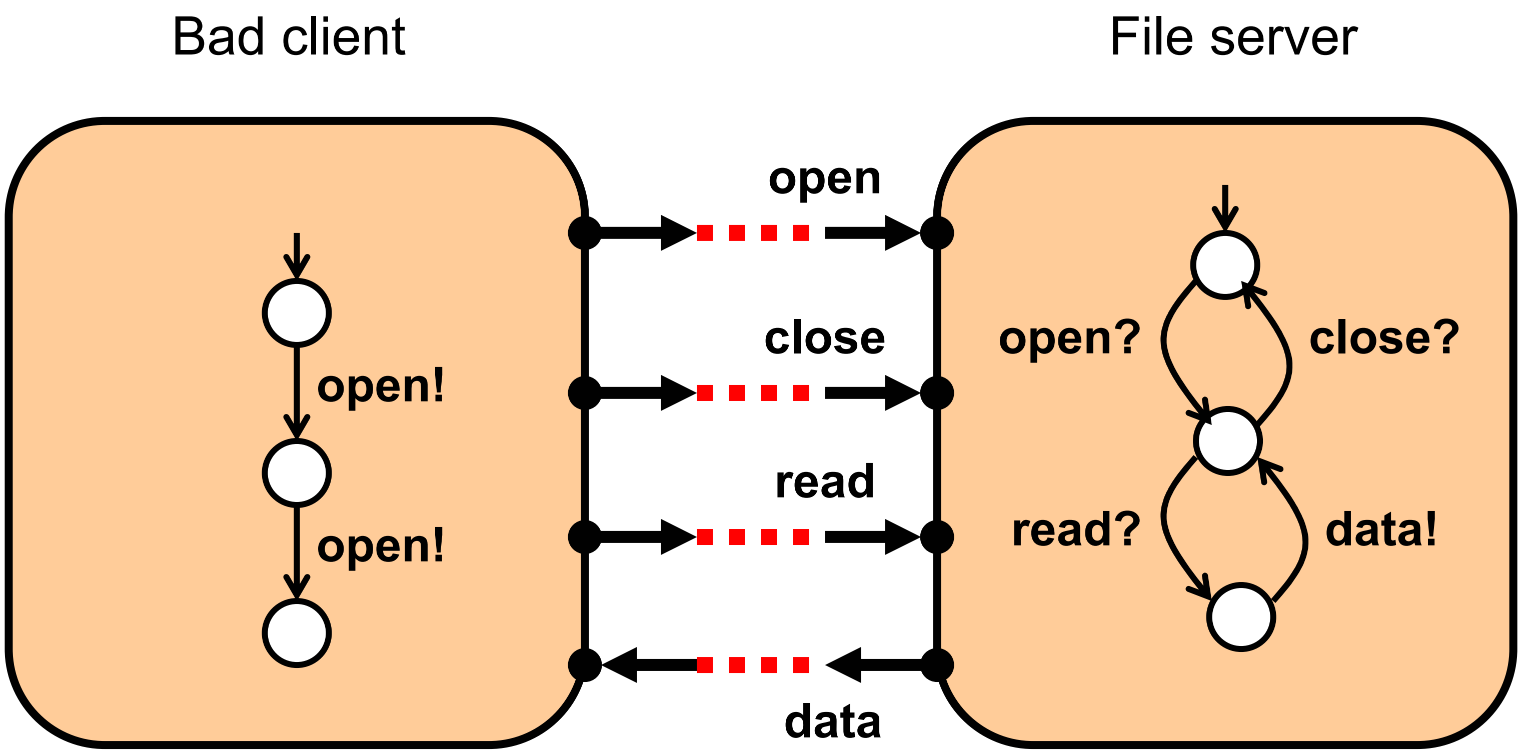
File server



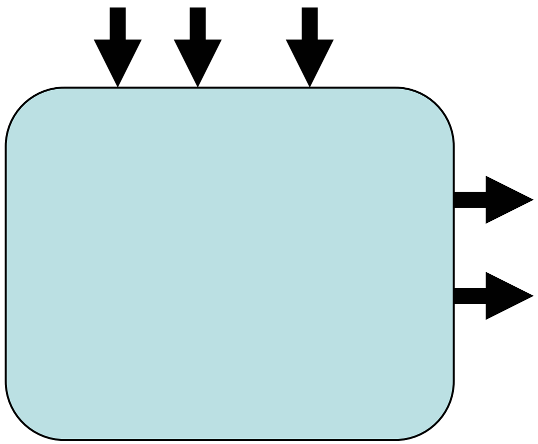
Interface Compatibility



Interface Compatibility



Incremental Design



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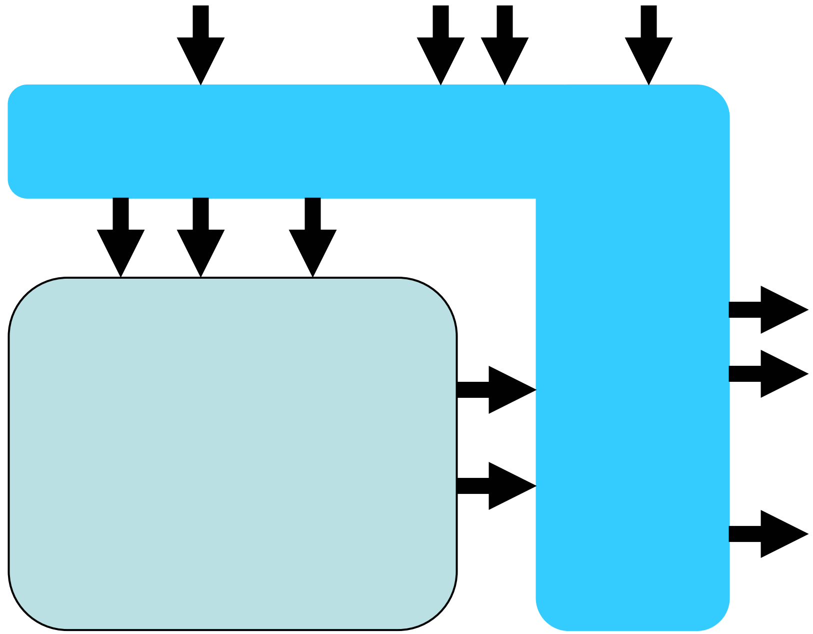

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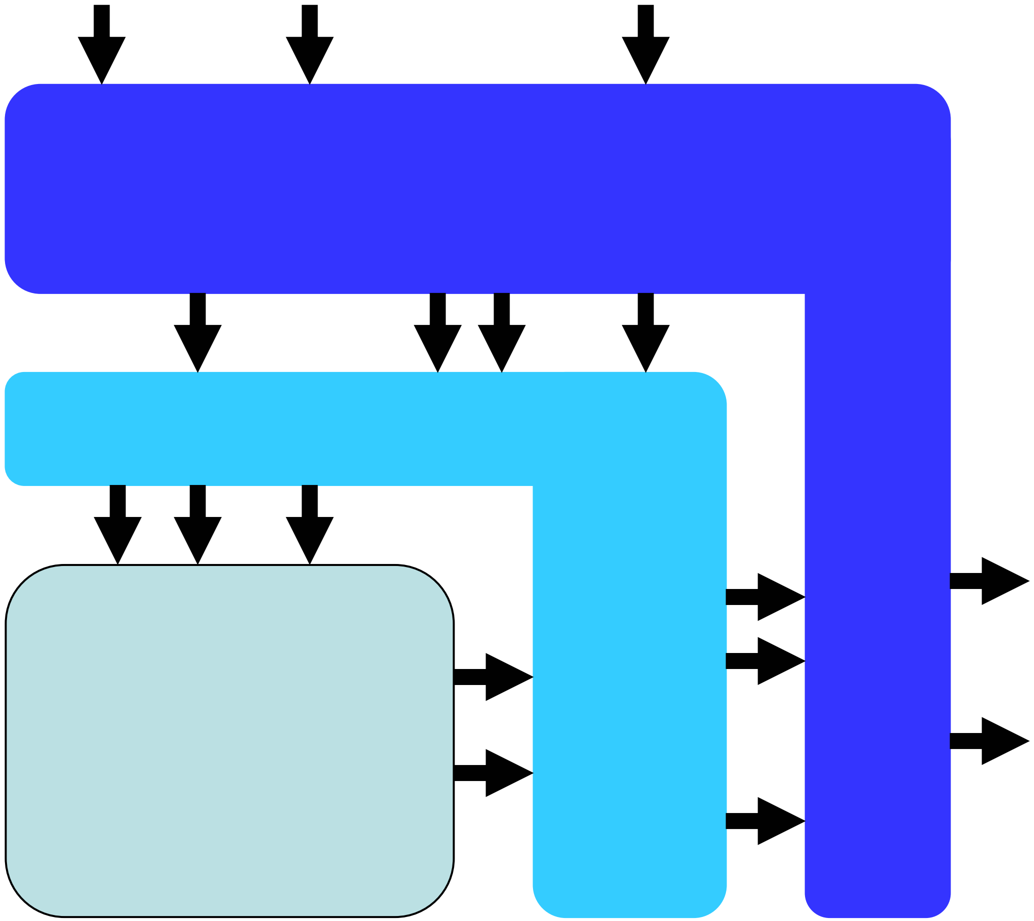

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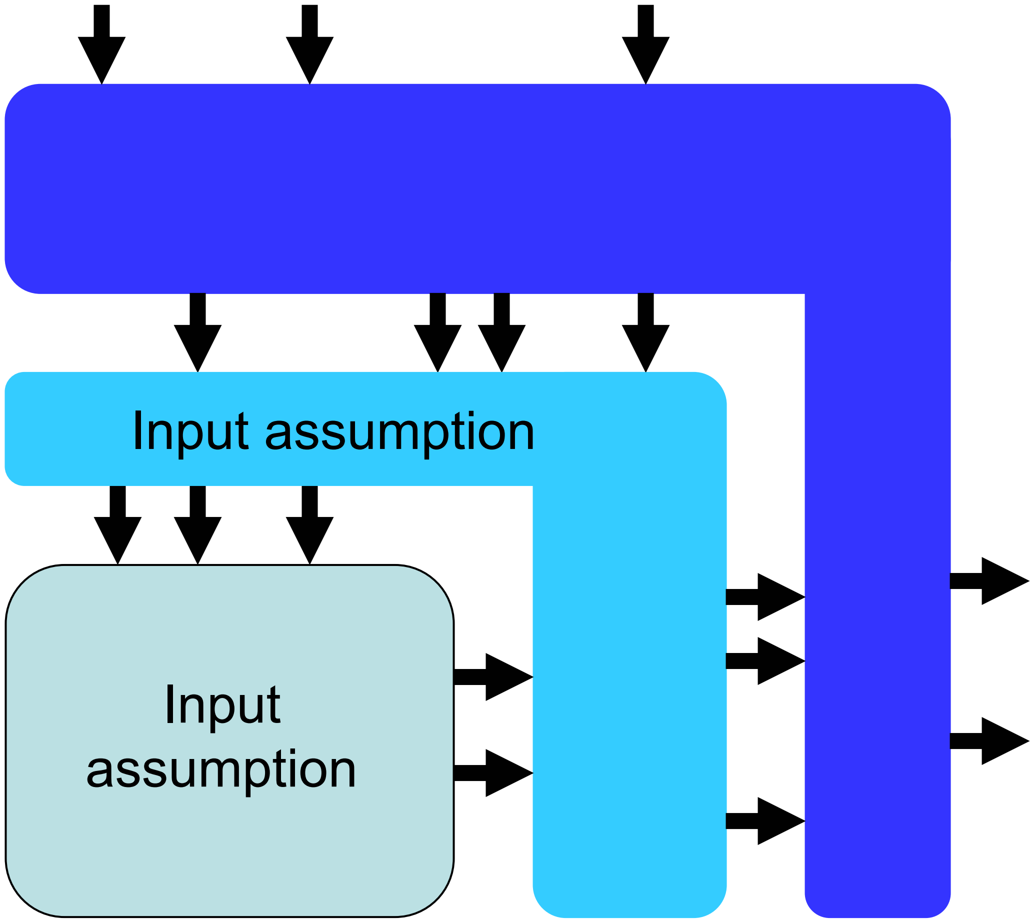

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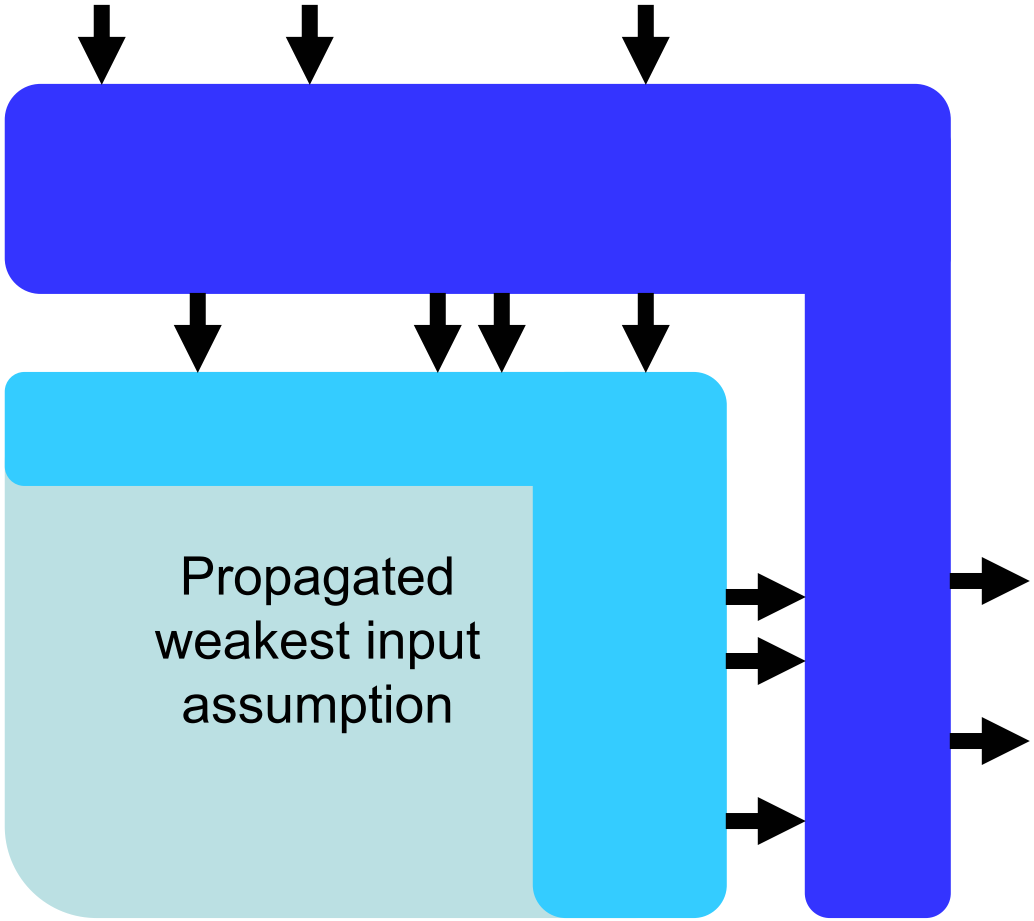
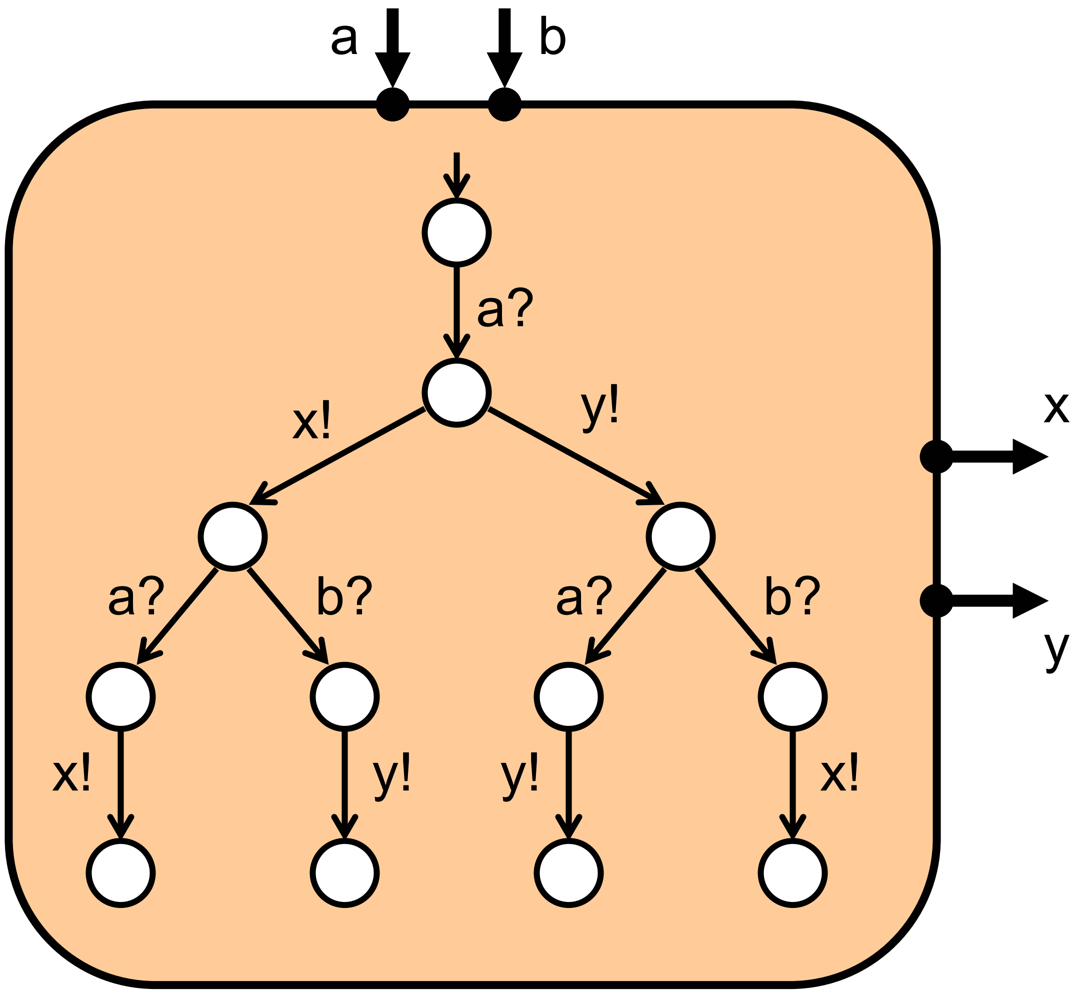


Input Assumption Propagation



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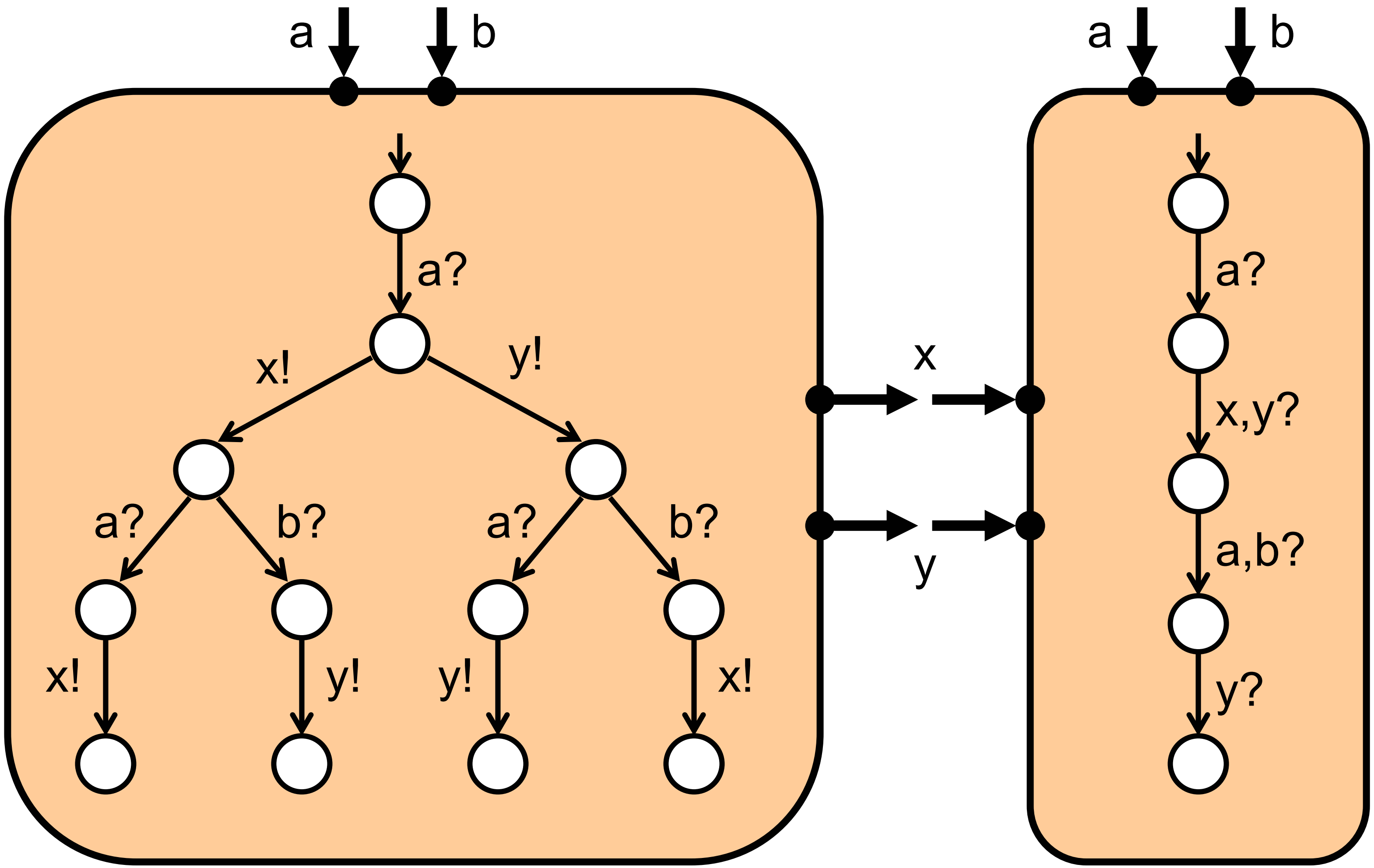

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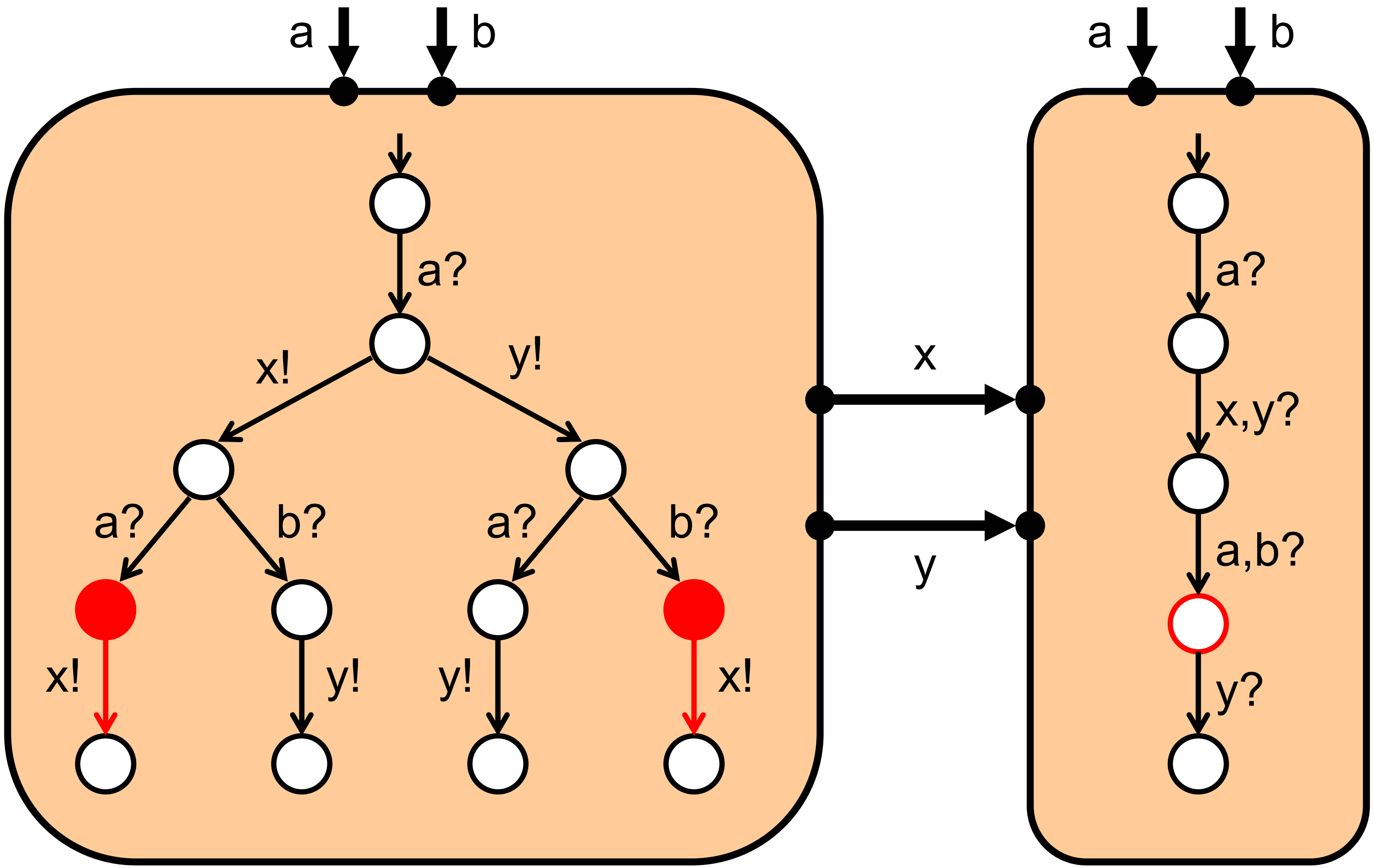
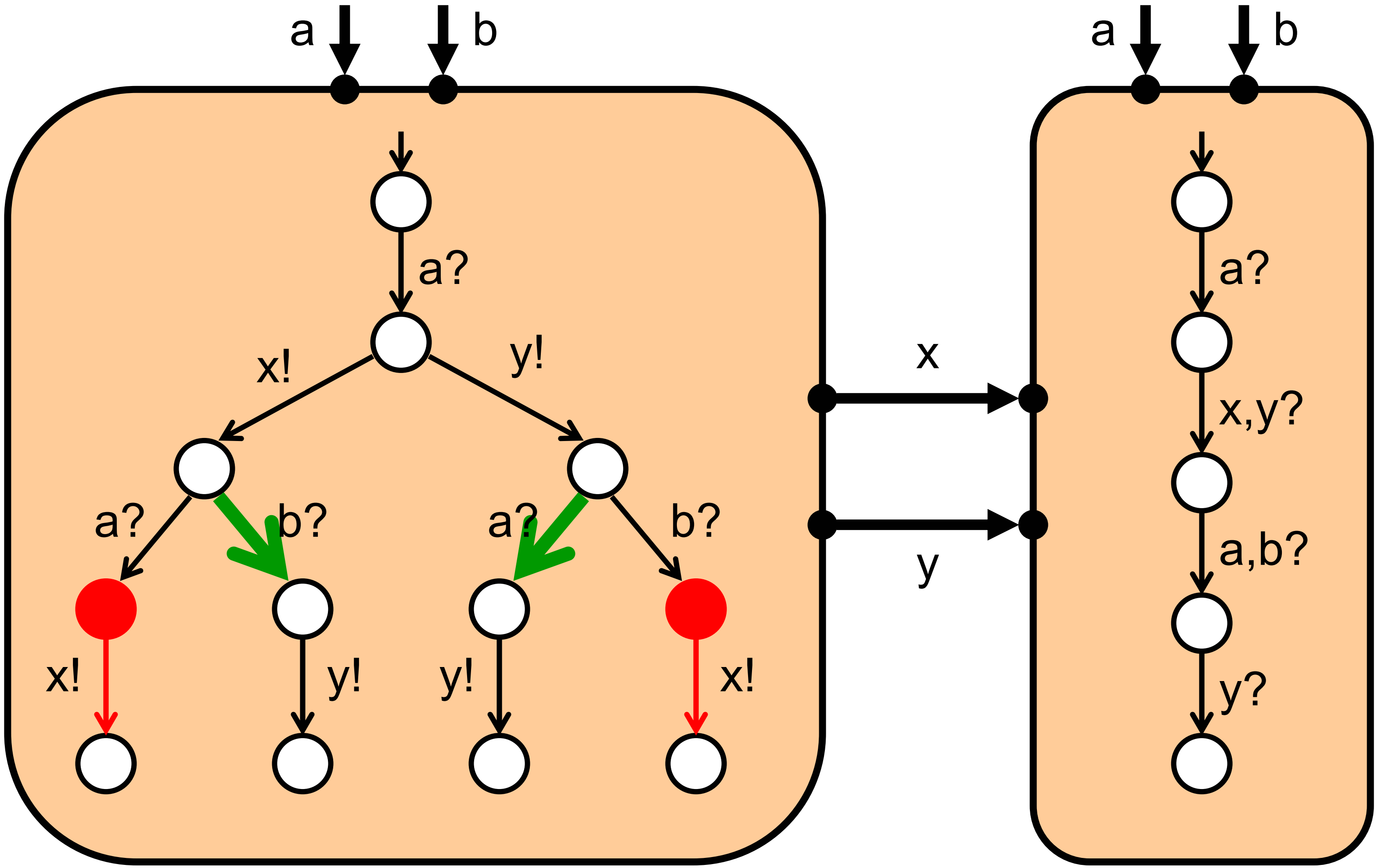
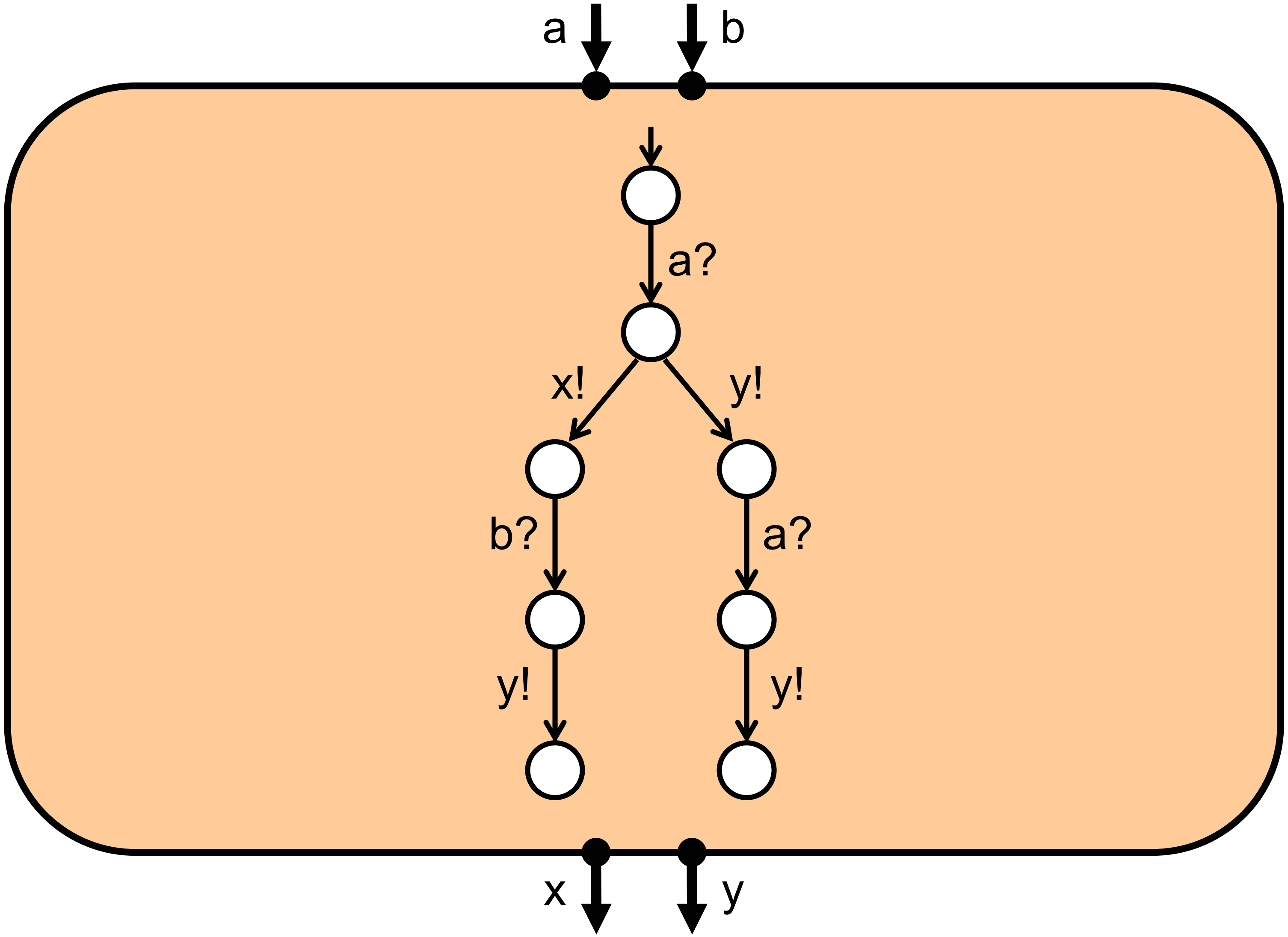


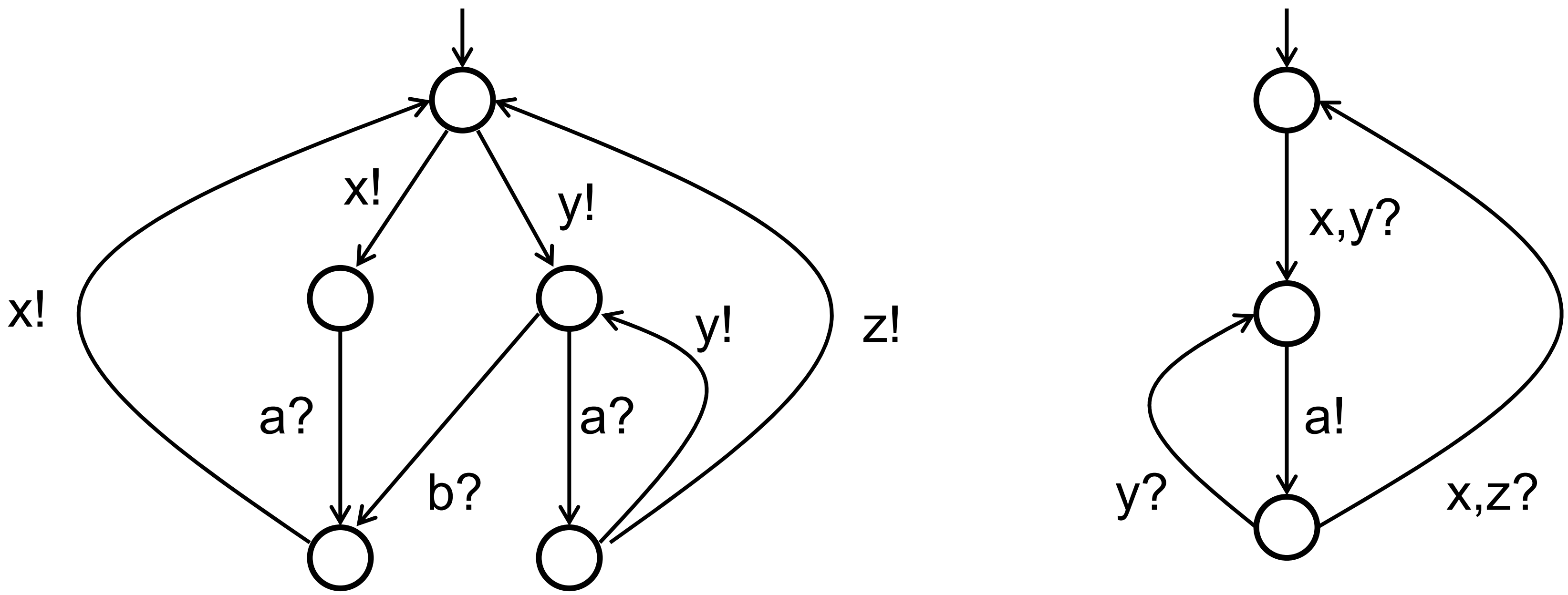
Two interfaces are compatible if they can be used together in ***some*** environment.



The Composite Interface

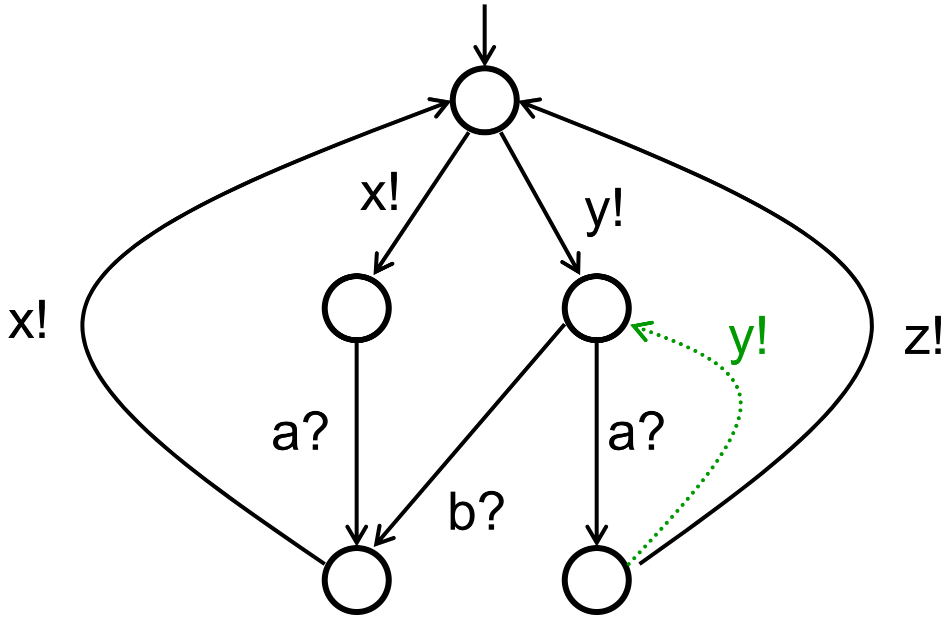


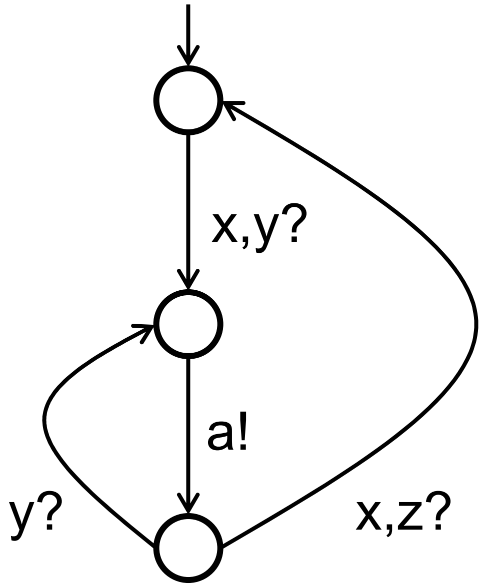
Refinement



Every legal environment should be a legal environment of the refined process.

Refinement





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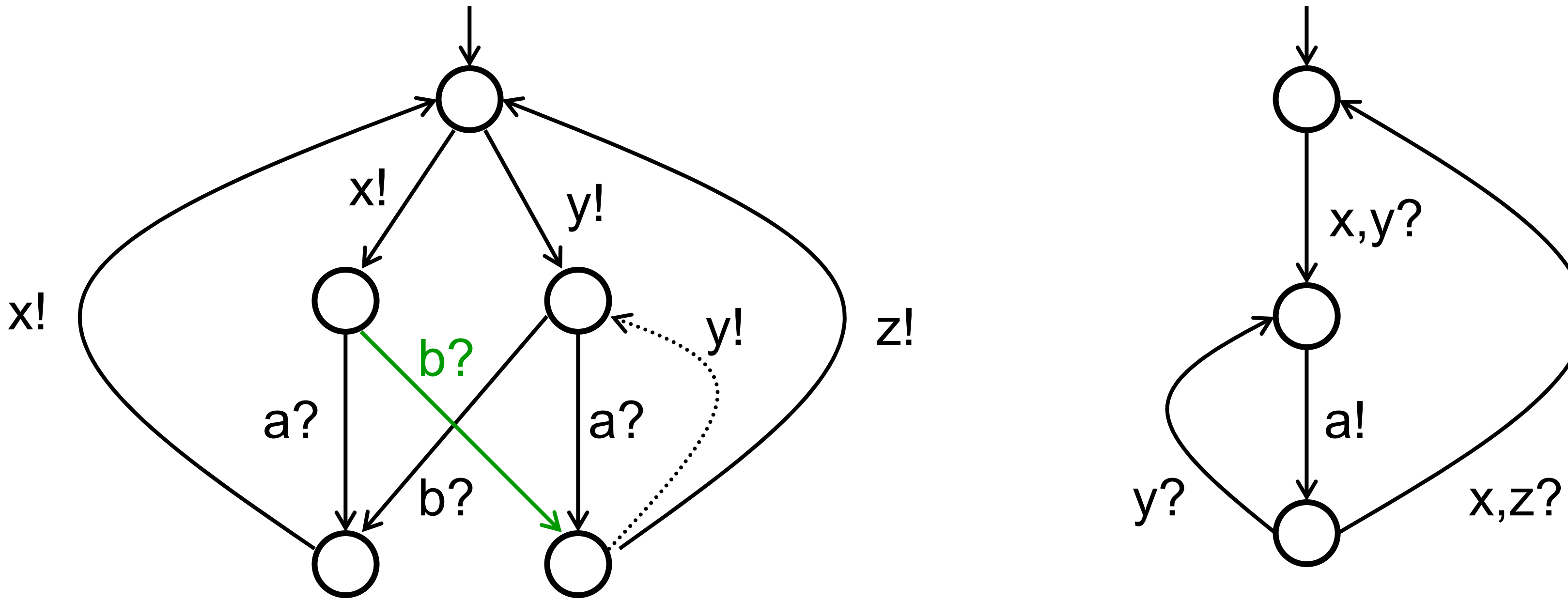
Refinement



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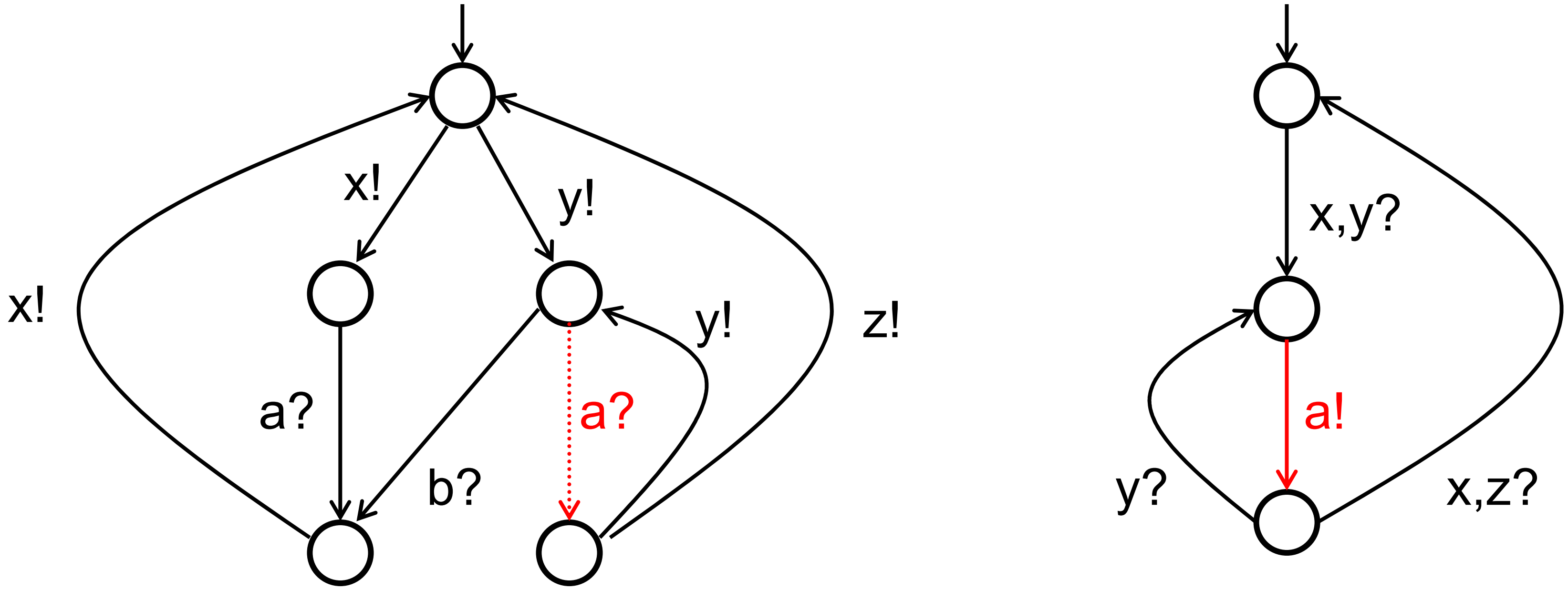

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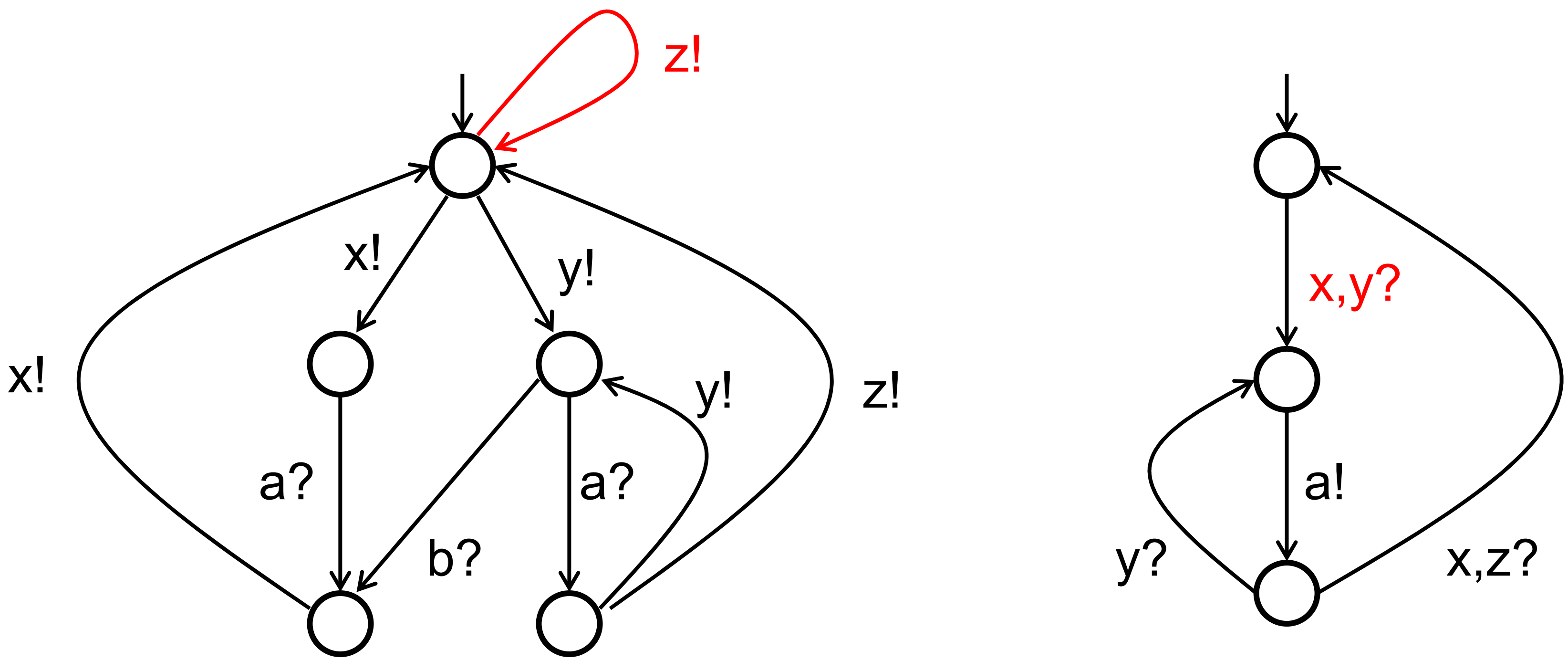

Every legal environment should be a legal environment of the refined process.

Interface Refinement: I/O Alternating Simulation

$A' \leq A$

iff

for all outputs o, if A' –o!-> B' , then there exists B such that A –o!-> B and $B' \leq B$.

Interface Refinement: I/O Alternating Simulation

$A' \leq A$

iff

1. for all inputs i, if A –i?-> B , then there exists B′ such that A′ –i?-> B′ and $B' \leq B$,

and

2. for all outputs o, if A′ –o!-> B′ , then there exists B such that A –o!-> B and $B' \leq B$.

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and

2. for all outputs o, if A' –o!-> B' , then there exists B such that A –o!-> B and $B' \leq B$.

Every environment (*i.e.,* input strategy that avoids deadlock) for A is an environment for A' [Alur/H/Kupferman/Vardi].

The Principle of Independent Implementability

If A and B is are compatible and $A' \leq A$ and $B' \leq B$, then *A' and B' are compatible* and $A'||B' \leq A||B$.

$A' \leq A$ … A' refines / implements A

The Principle of Independent Implementability

If A and B is are compatible and $A' \leq A$ and $B' \leq B$, then *A' and B' are compatible* and $A'||B' \leq A||B$.

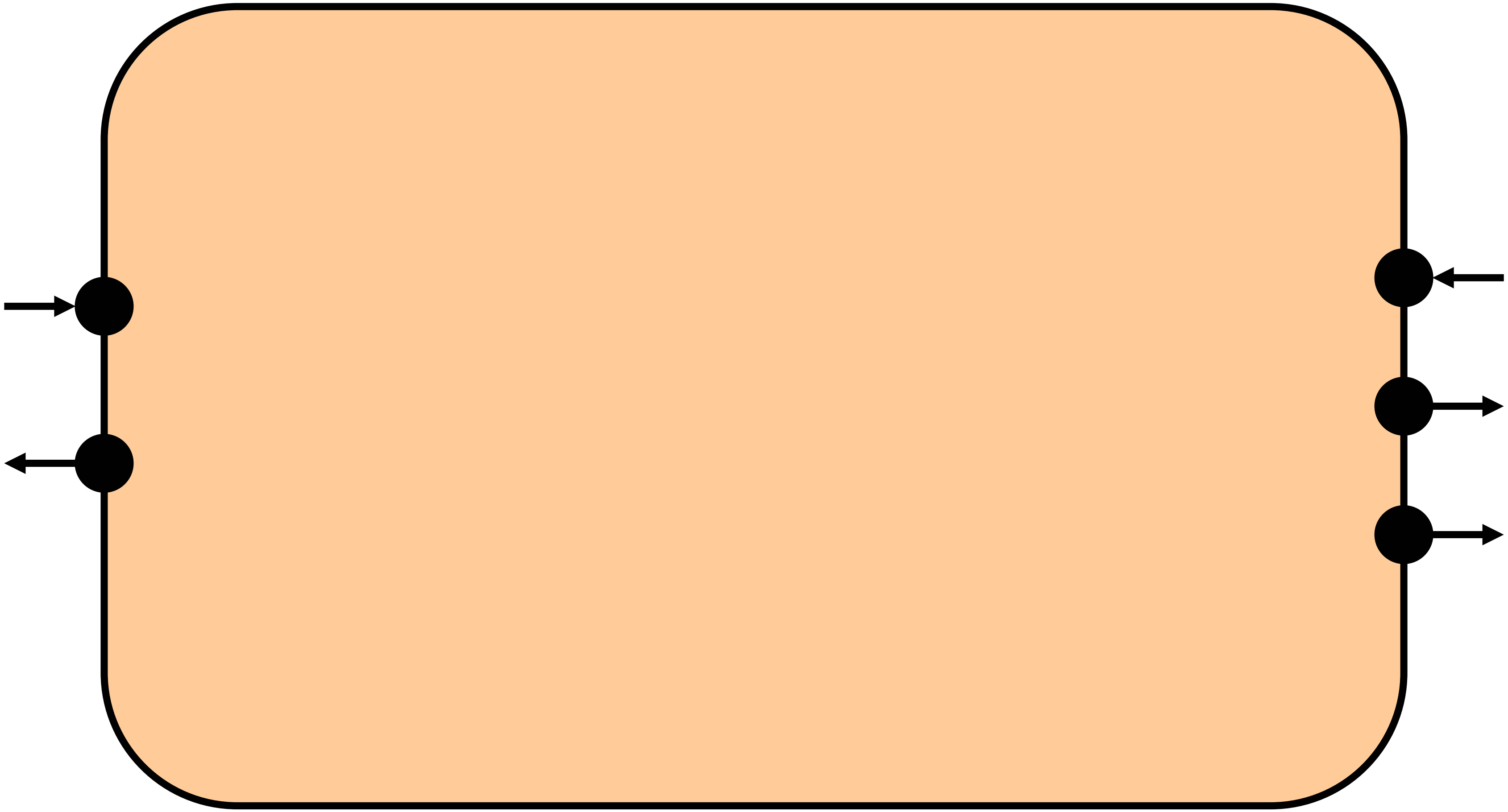
$A' \leq A$ … A' refines / implements A

This is a theorem if

-A, B, A', B' are two-player games Input vs. Output

-two games are compatible if player Input has a winning strategy in the composite game

Interface-based Design



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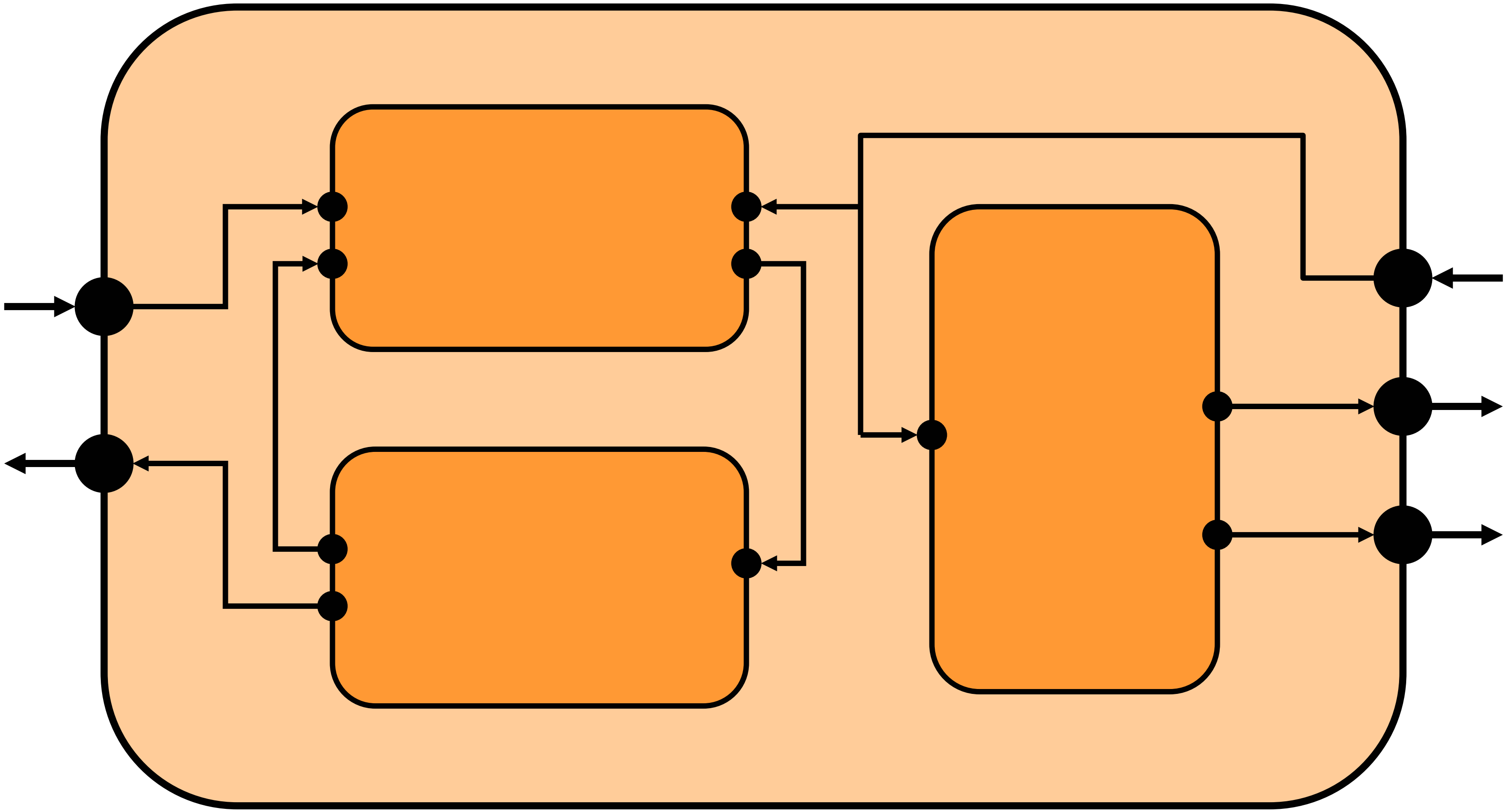

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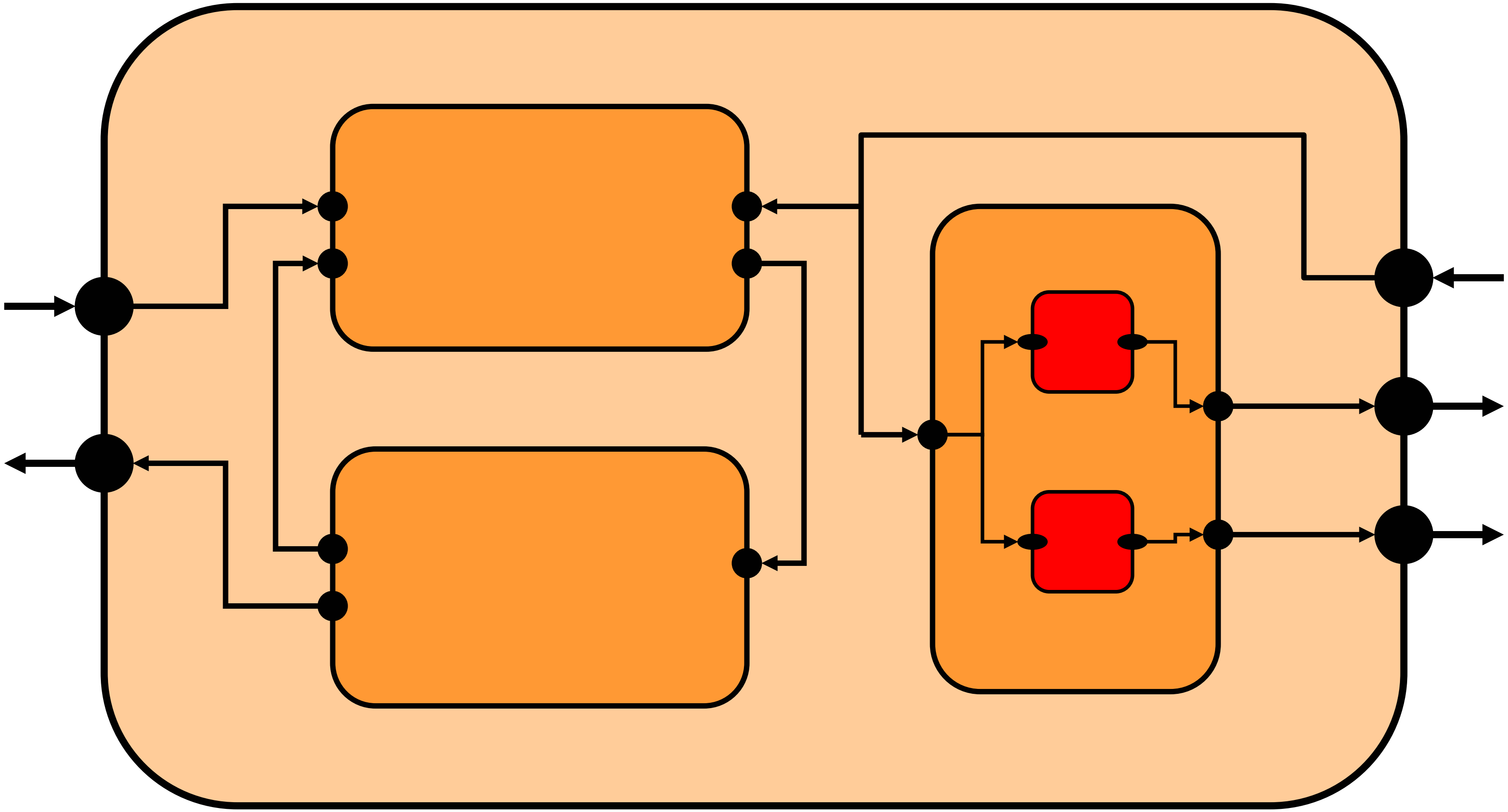

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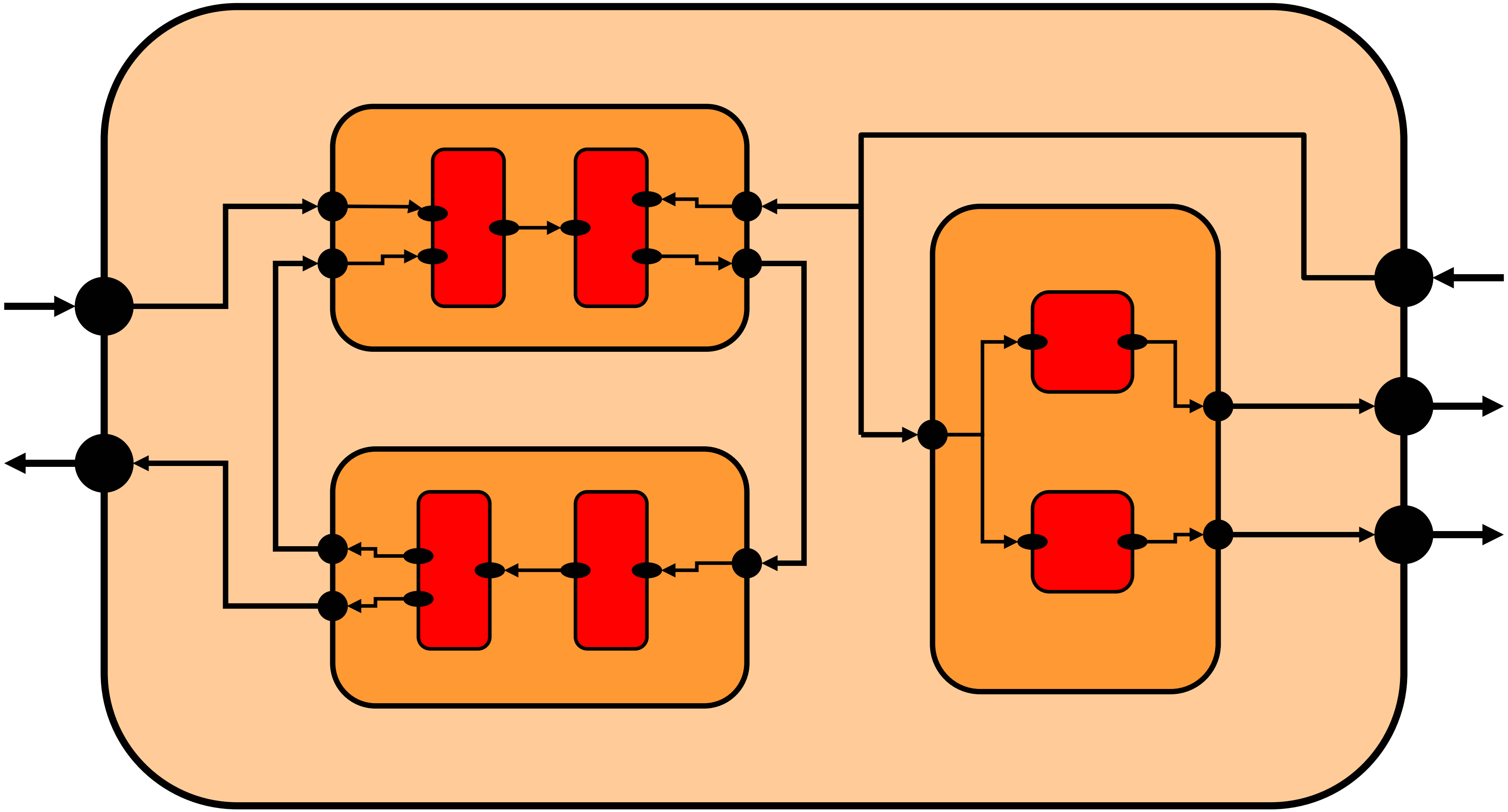

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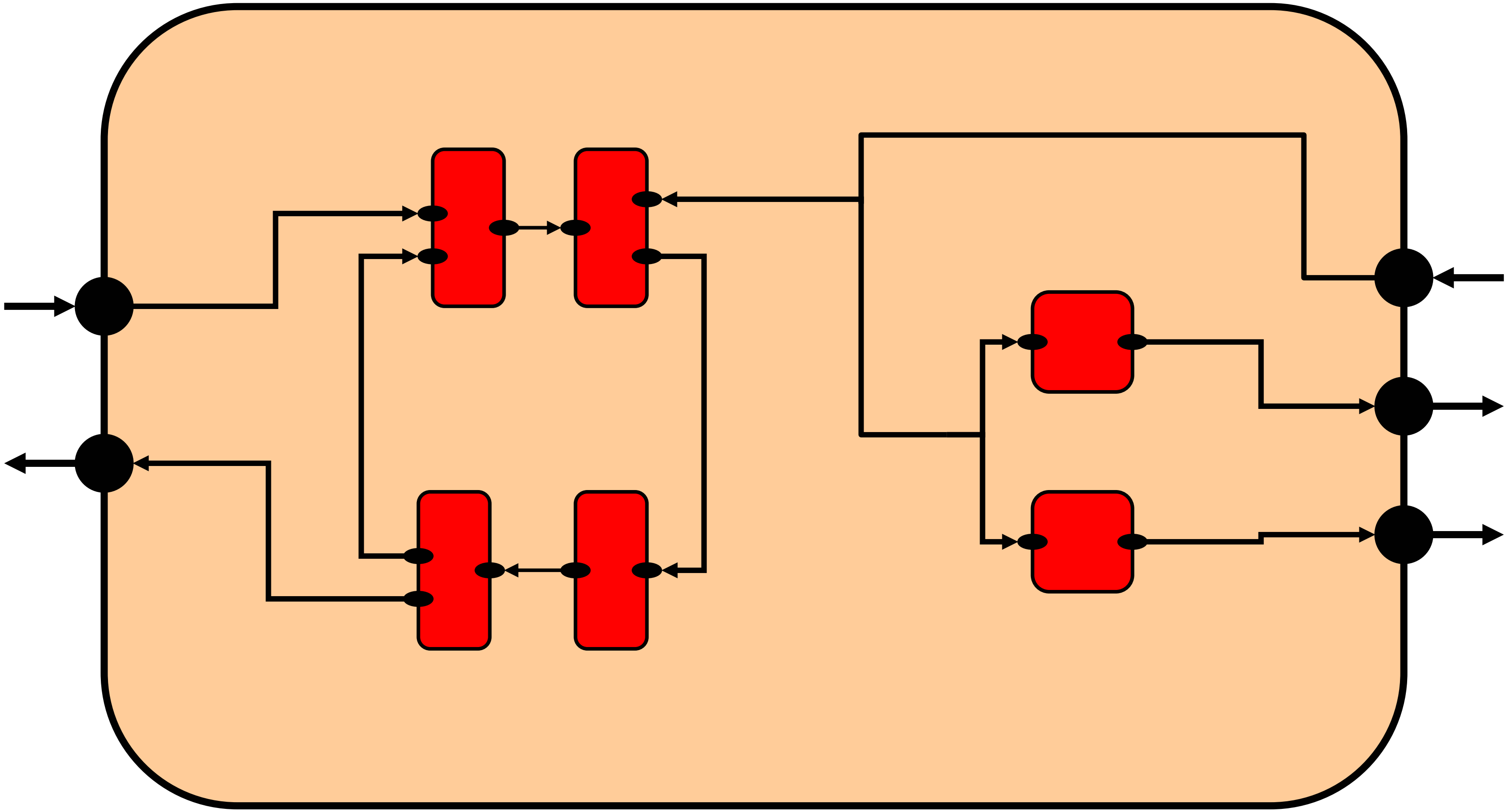

Summary

There are many models of computation (e.g. pushdown, timed, stochastic) and many models of interaction (e.g. synchronous).

Similarly, there are many variants of games (e.g. concurrent vs. turn-based moves; pure vs. randomized strategies).

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There are many models of computation (e.g. pushdown, timed, stochastic) and many models of interaction (e.g. synchronous).

Similarly, there are many variants of games (e.g. concurrent vs. turn-based moves; pure vs. randomized strategies).

The technical details are different, but to ask and answer the kind of questions we discussed, the only important feature of a model is the presence of multiple players.

References

Interface Automata: de Alfaro, H FSE 2001
Secure Equilibria: Chatterjee, H, Jurdzinski LICS 2004