FORTE'13 | Firenze, Italy

Verification of

Directed Acyclic Ad-Hoc Networks

Othmane
Rezine

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Verification of

Directed Acyclic Ad-Hoc Networks

Parosh Abdulla

Mohammed Faouzi Atig

Othmane Rezine

Ad-Hoc Networks

Directed Acyclic

Ad-Hoc Networks

Directed Acyclic

Ad-Hoc Networks

- Model
- Transition System
- Reachability

Directed Acyclic

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Directed Acyclic

Ad-Hoc Networks

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Direct

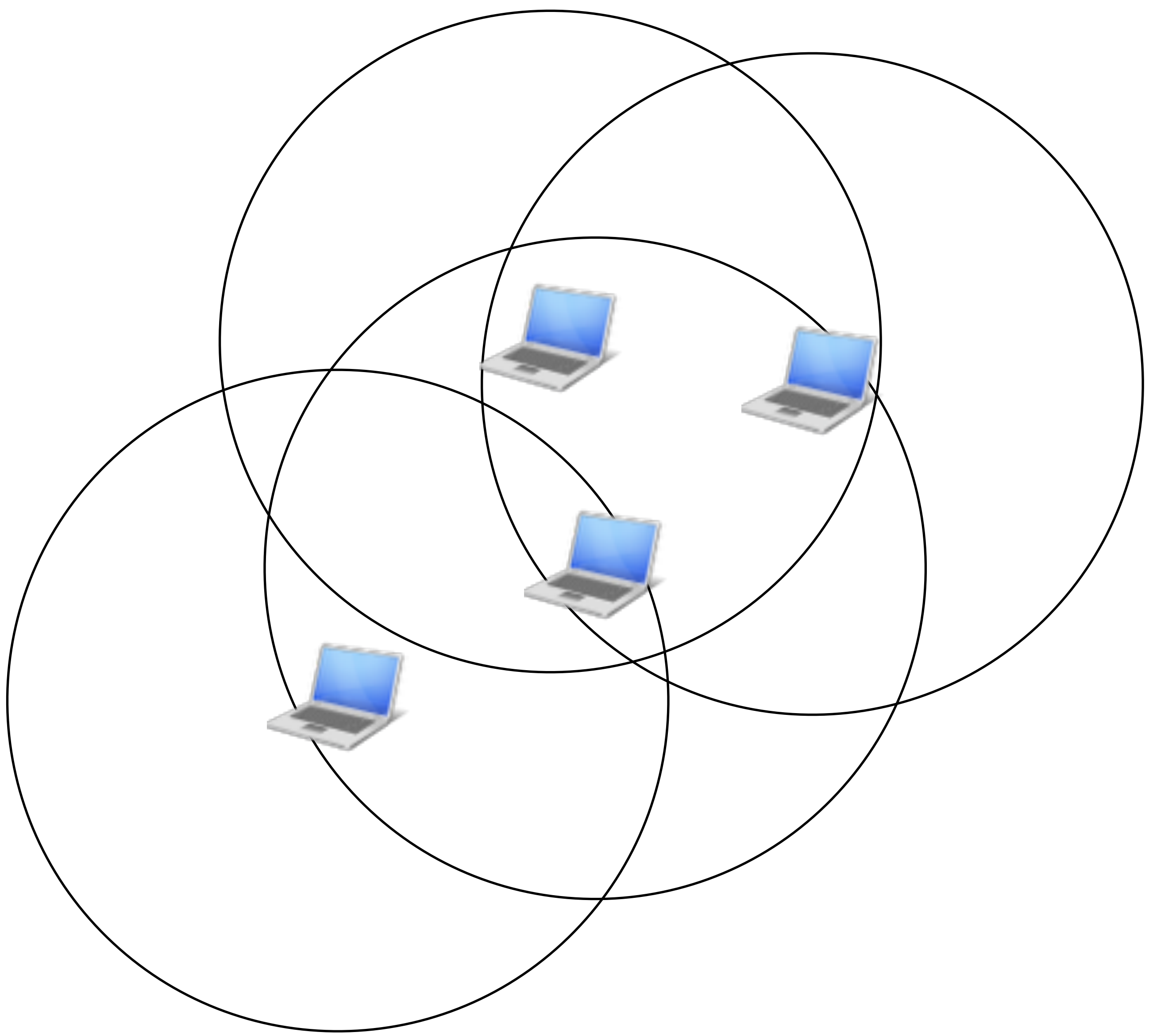
Ad-Hoc Networks

- Wireless nodes: laptop

Direct

Ad-Hoc Networks

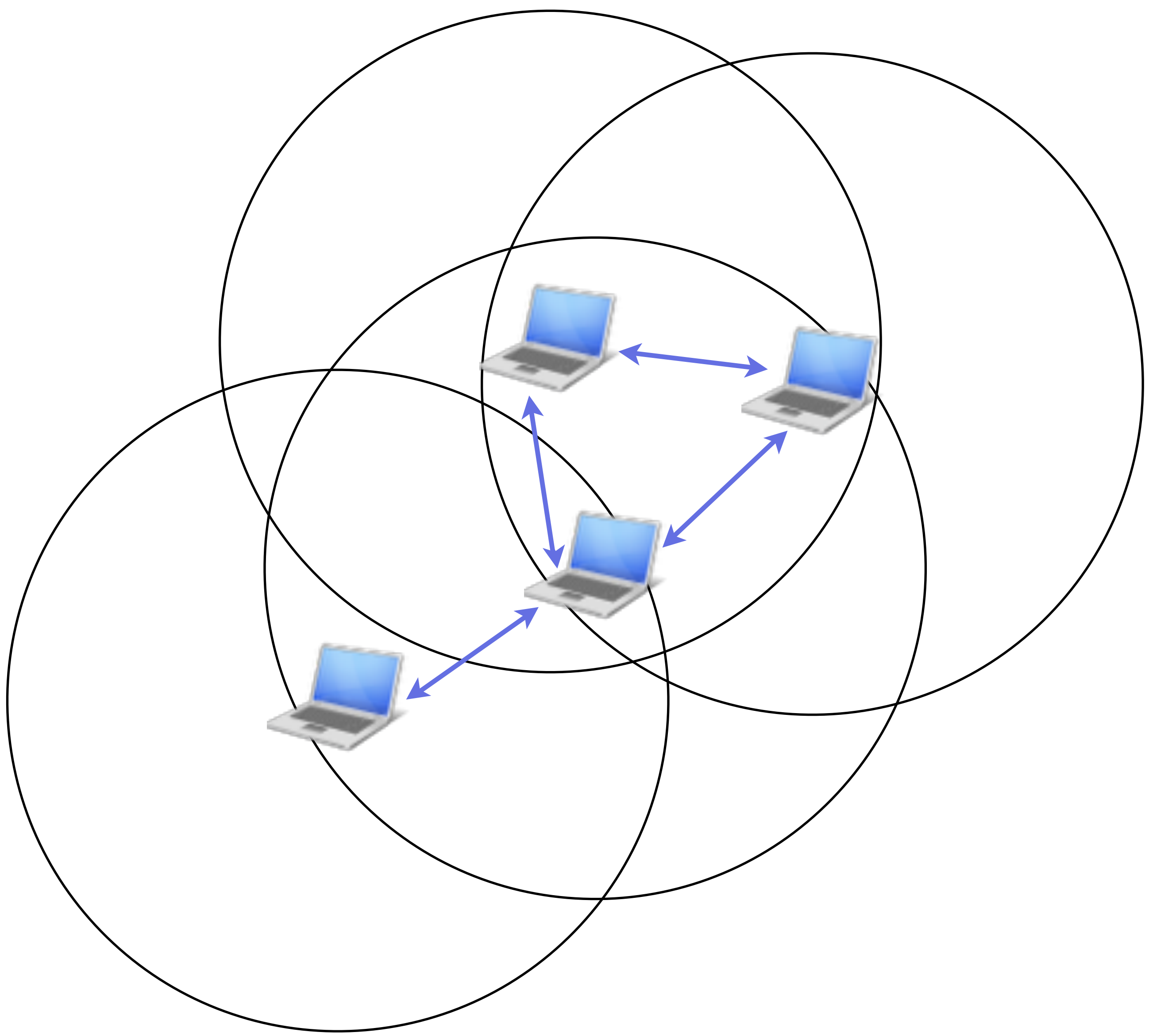
- Wireless nodes: laptop
- Radio Range



Direct

Ad-Hoc Networks

- Wireless nodes: laptop
- Radio Range
- Links / Topology



Direct

Ad-Hoc Networks

- Wireless nodes: laptop
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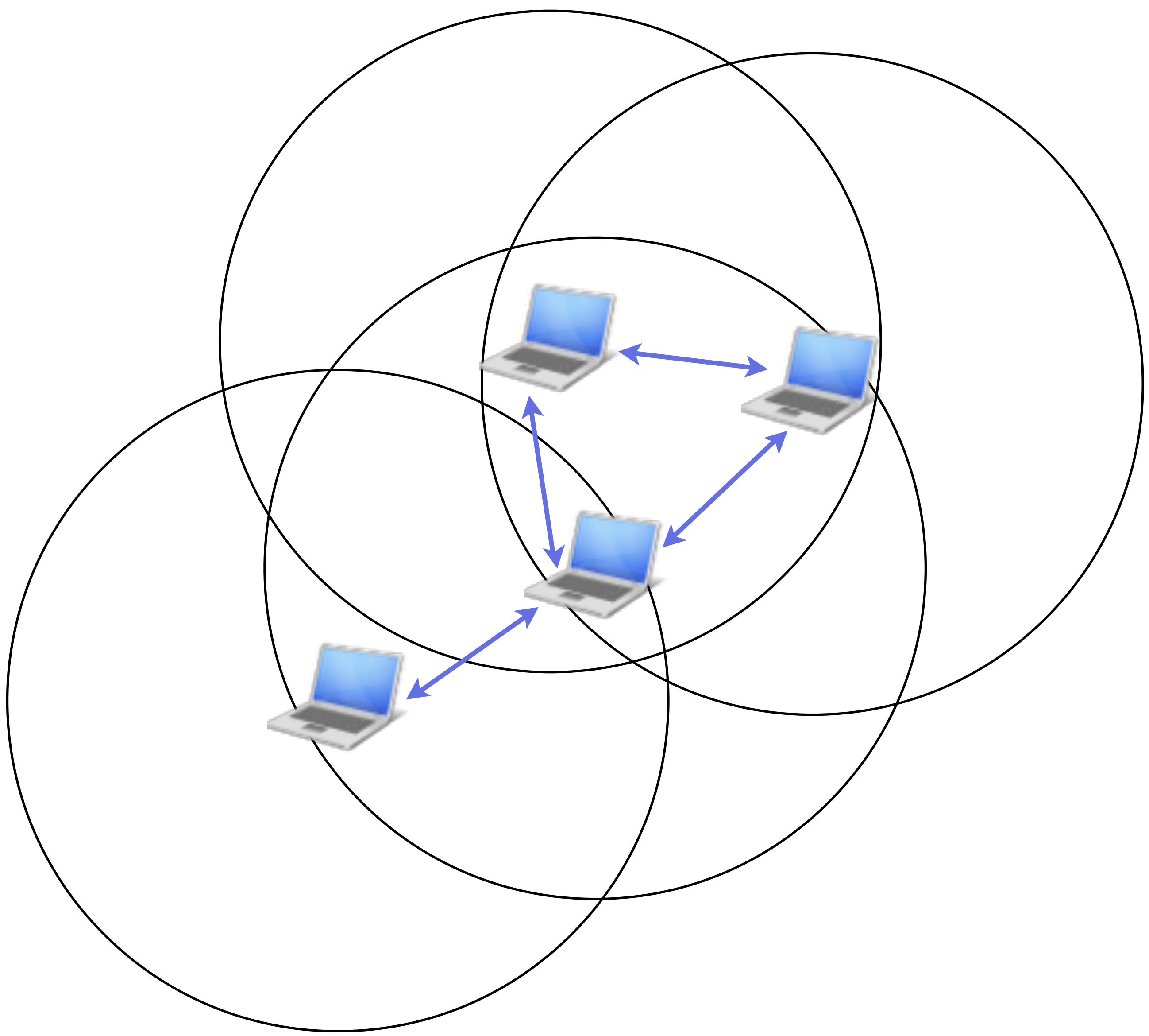
- Links / Topology
- Distributed management of the network



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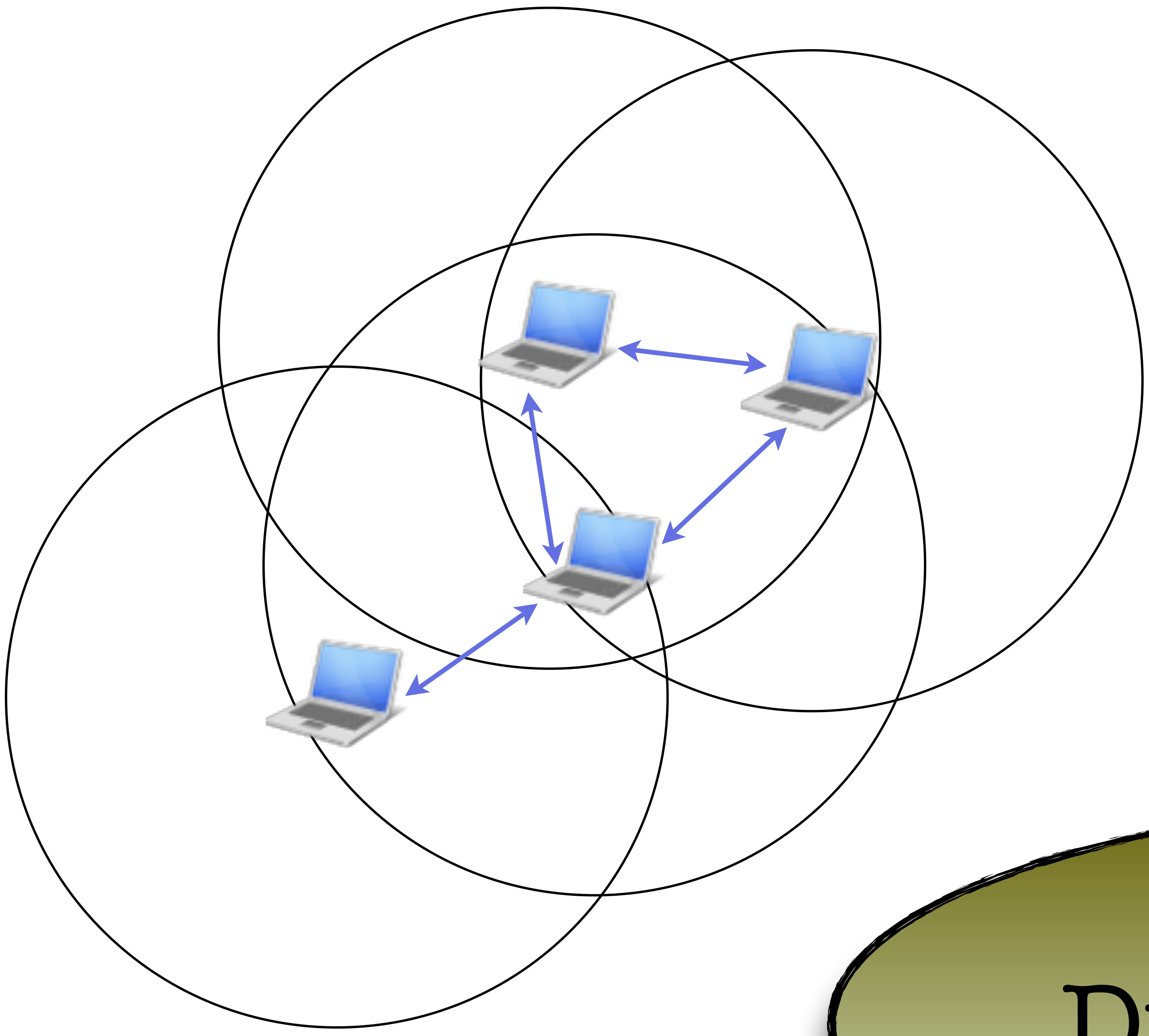

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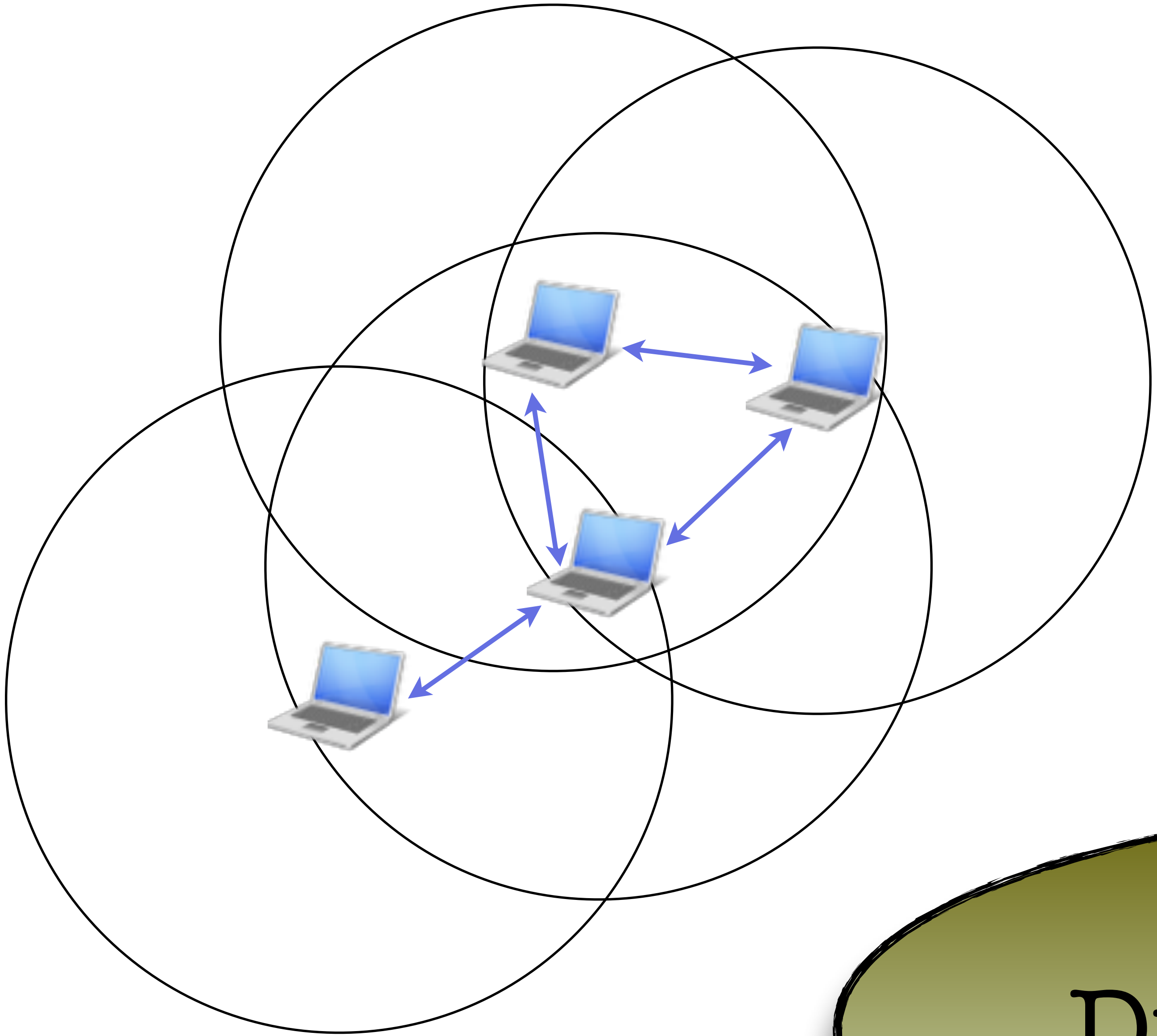
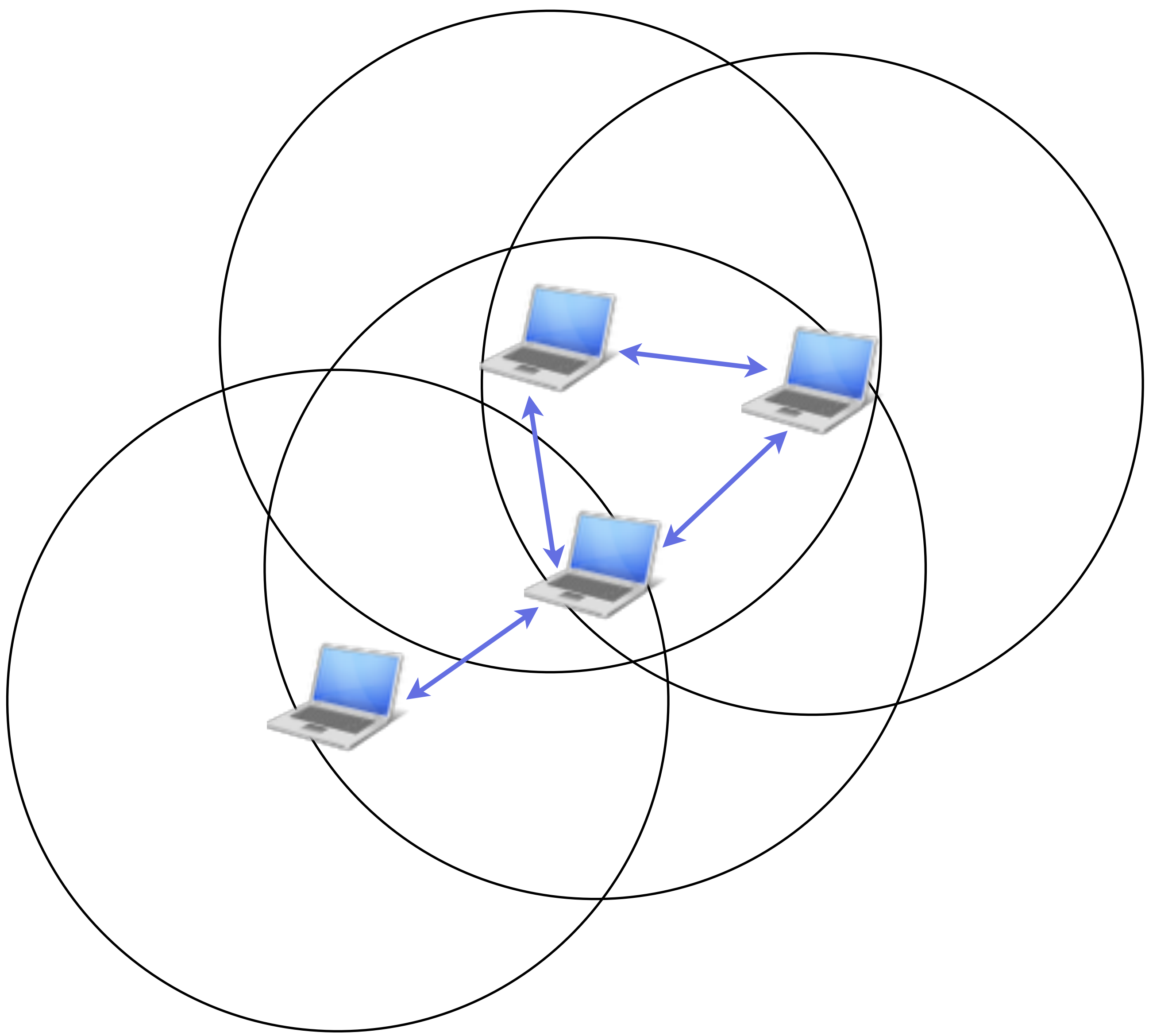


Applications

- Home area networks
- No telecom infrastructure

Ad-Hoc Networks

- Wireless nodes: laptop
- Radio Range
- Links / Topology
- Distributed management of the network



Direct

Ad-Hoc Networks

- Wireless nodes: ~~laptop~~ sensors
- Radio Range
- Links / Topology
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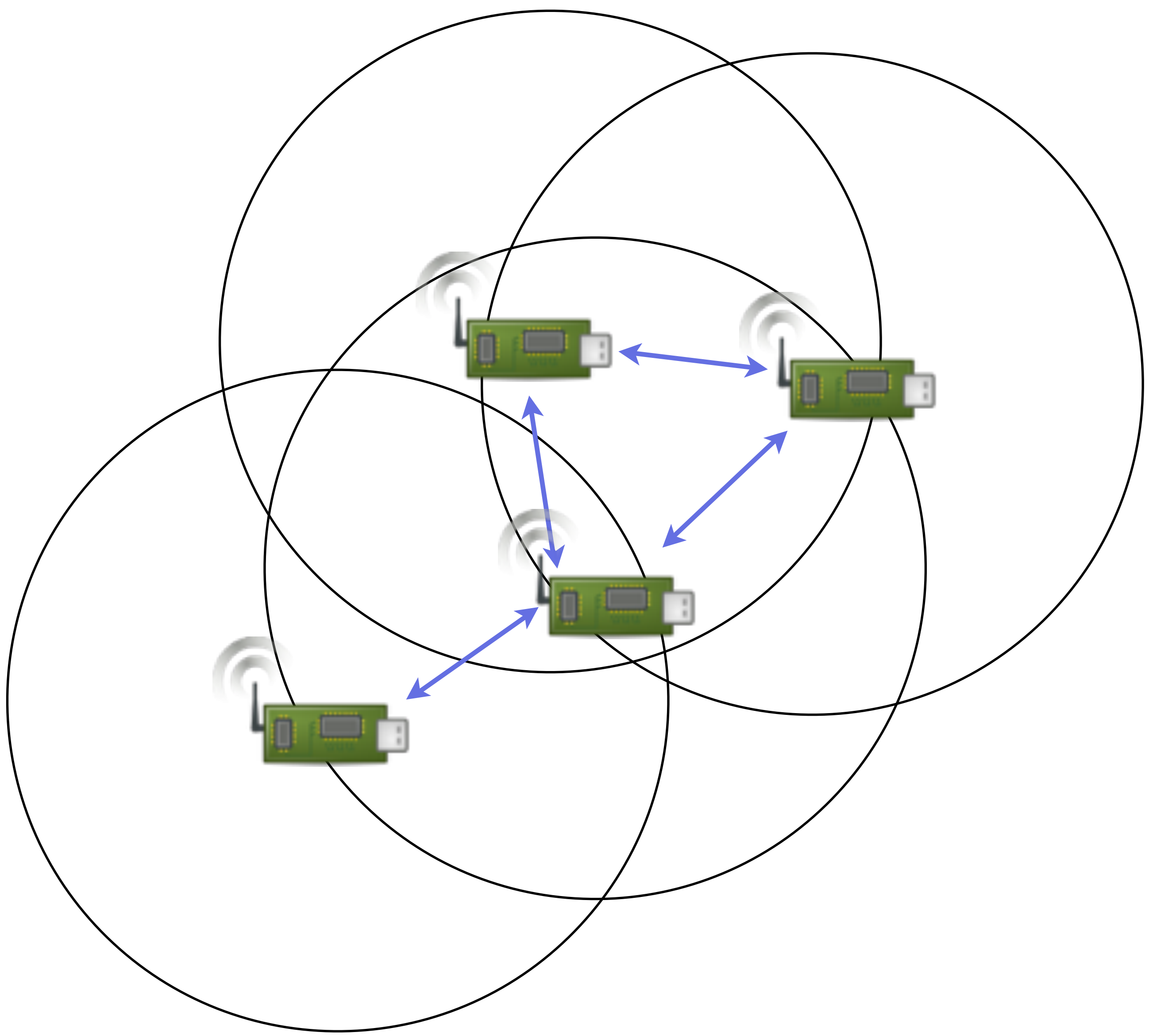

Direct

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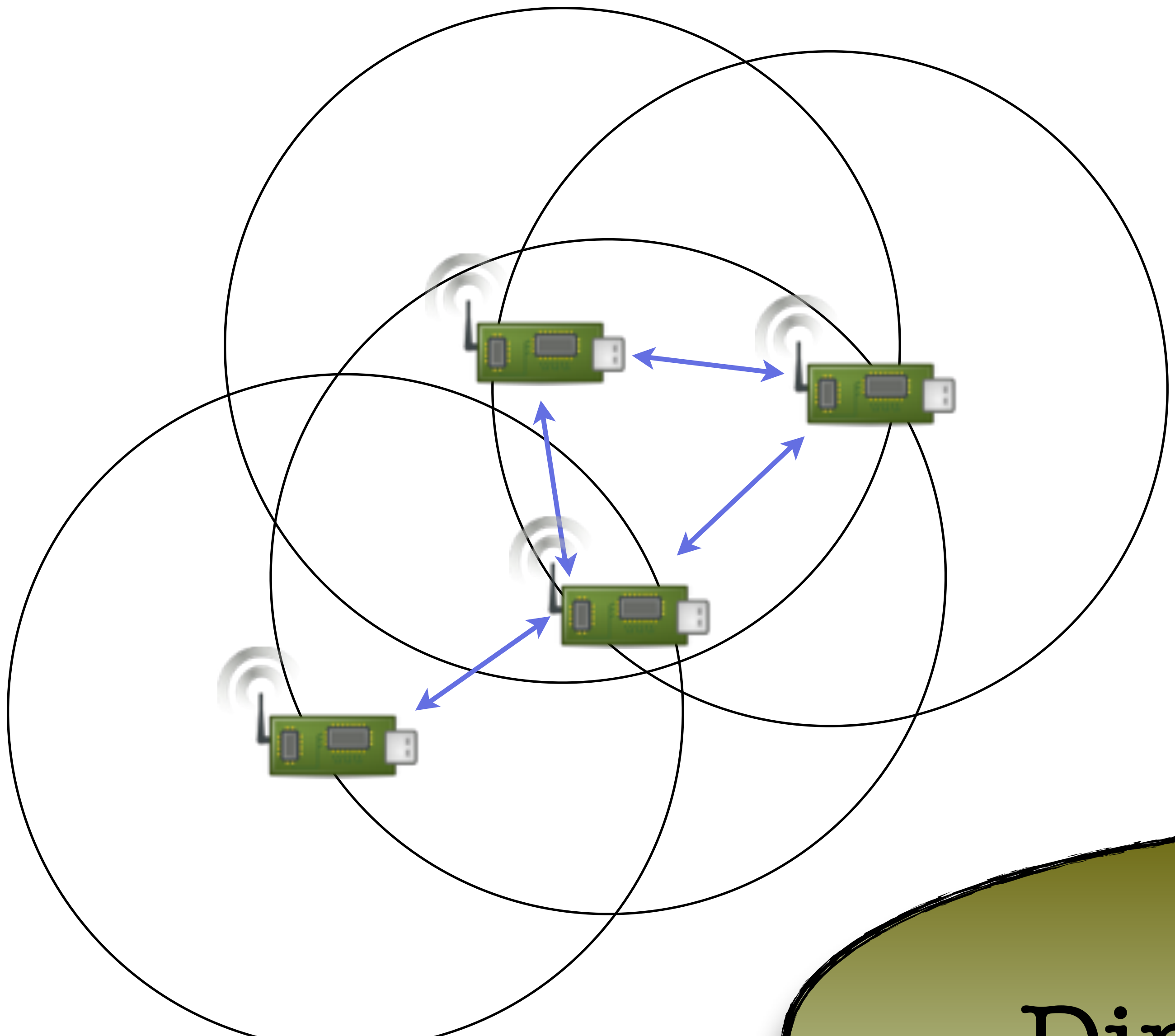

Ad-Hoc Networks

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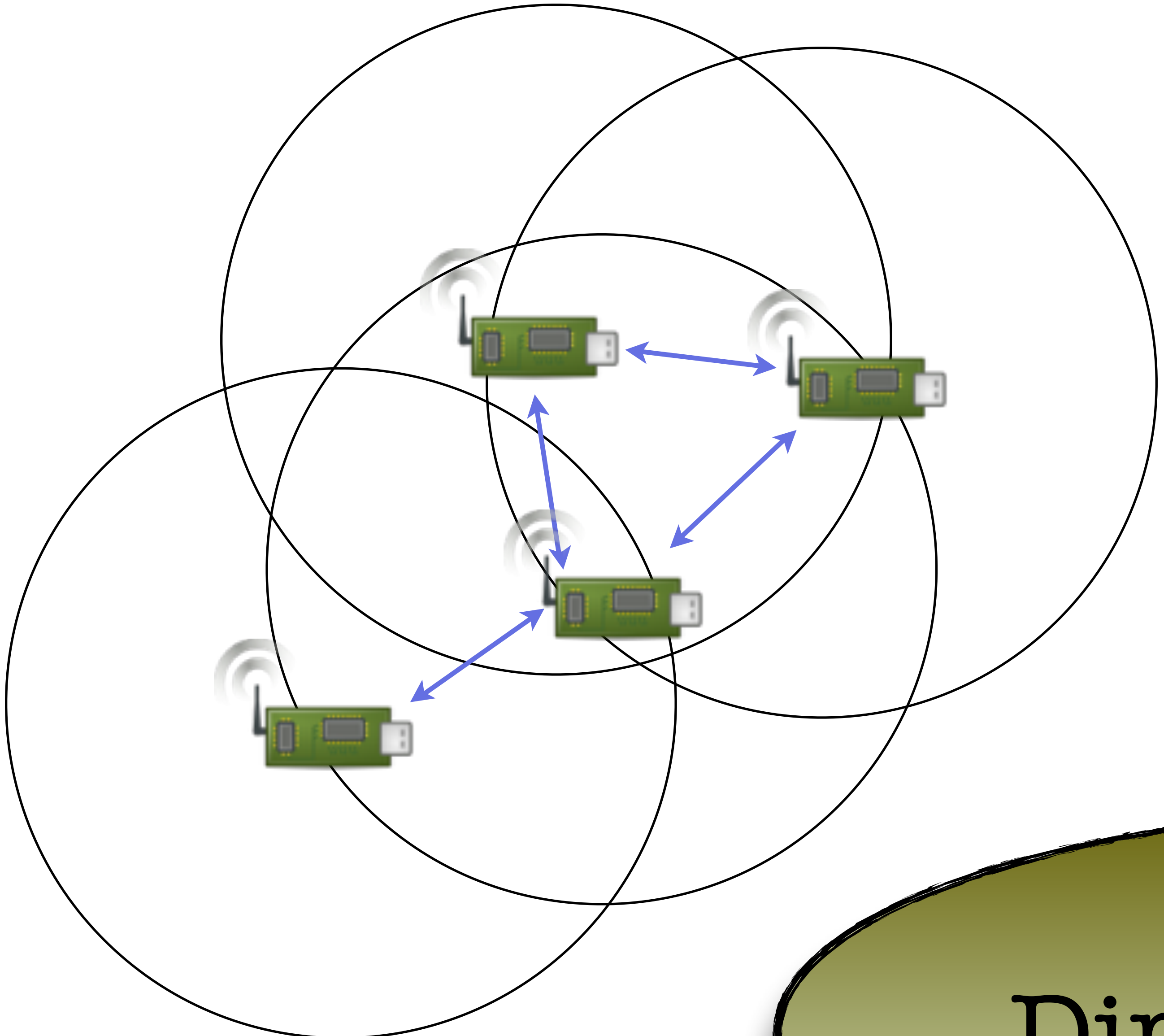

Applications

Monitoring of
- Seismic activity
- Heat
- Pollution

Ad-Hoc Networks

- Model
- Transition System
- Reachability

Direct

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Parameterized verification of ad-hoc networks
CONCUR'10

Ad-Hoc Networks

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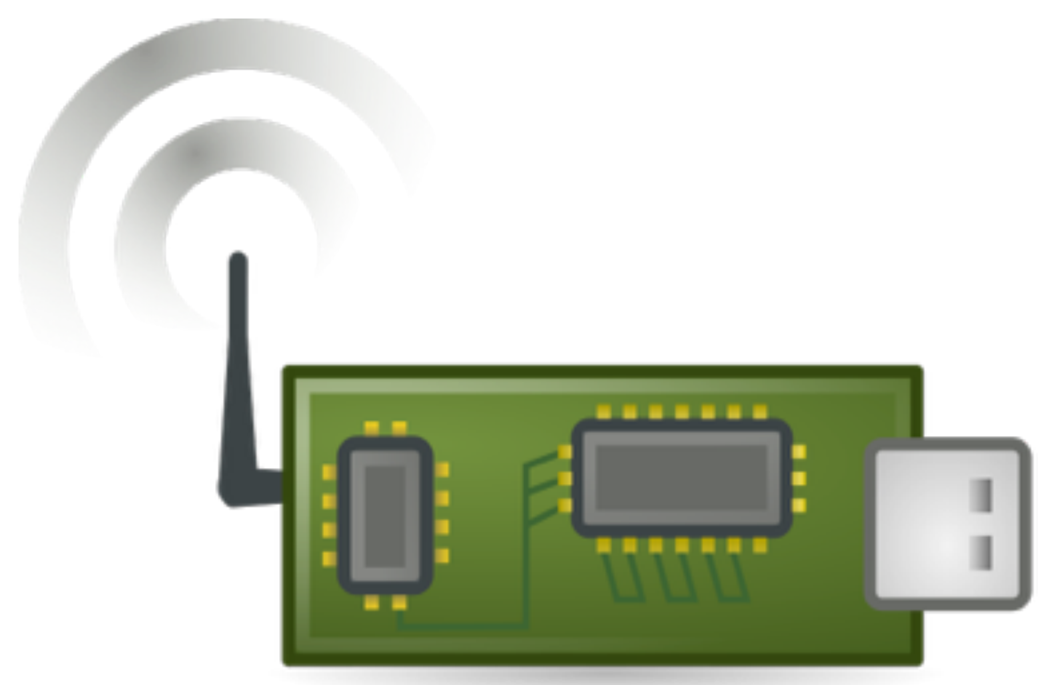
Model



Direct

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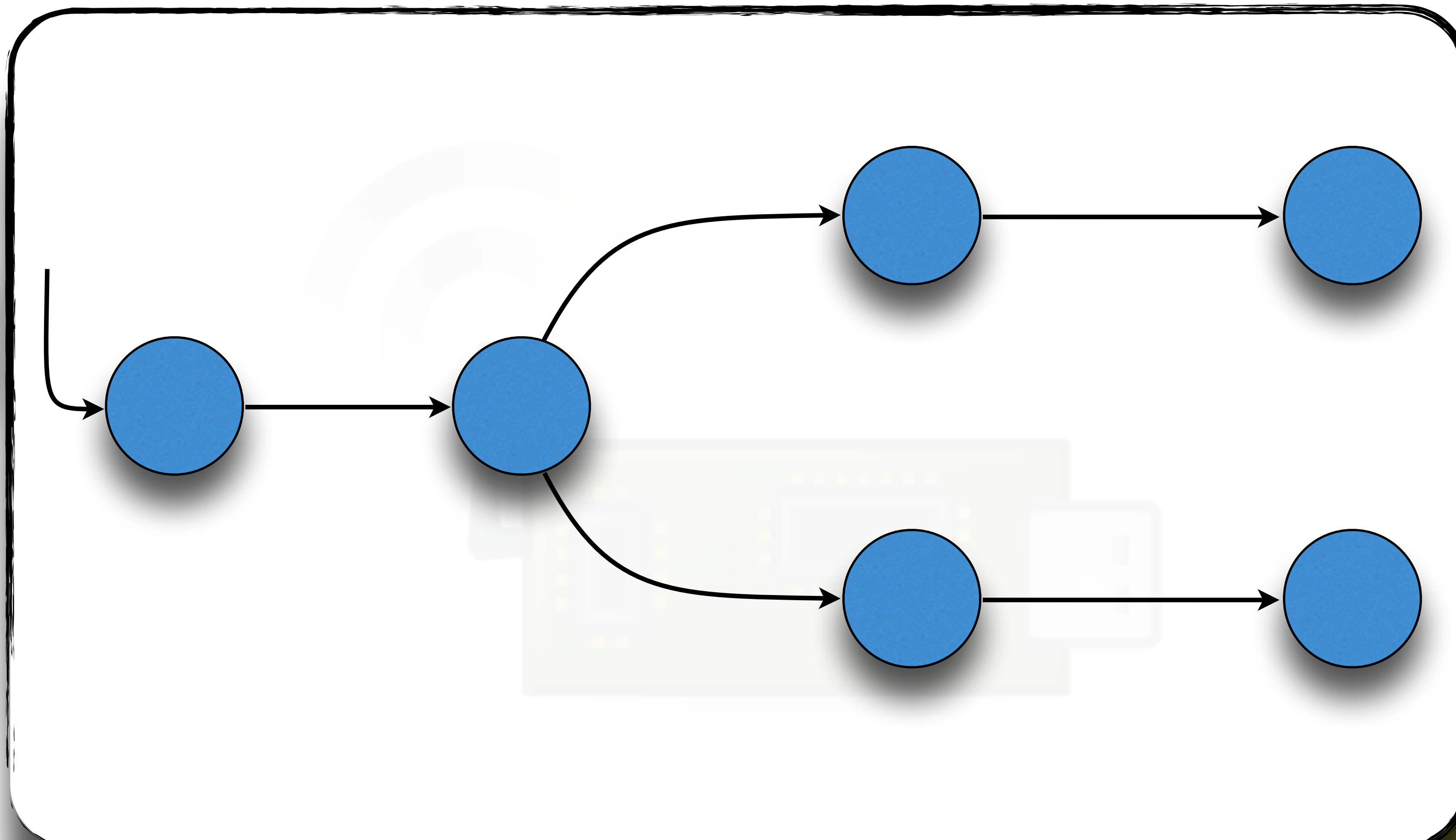
Model

Node:
Process



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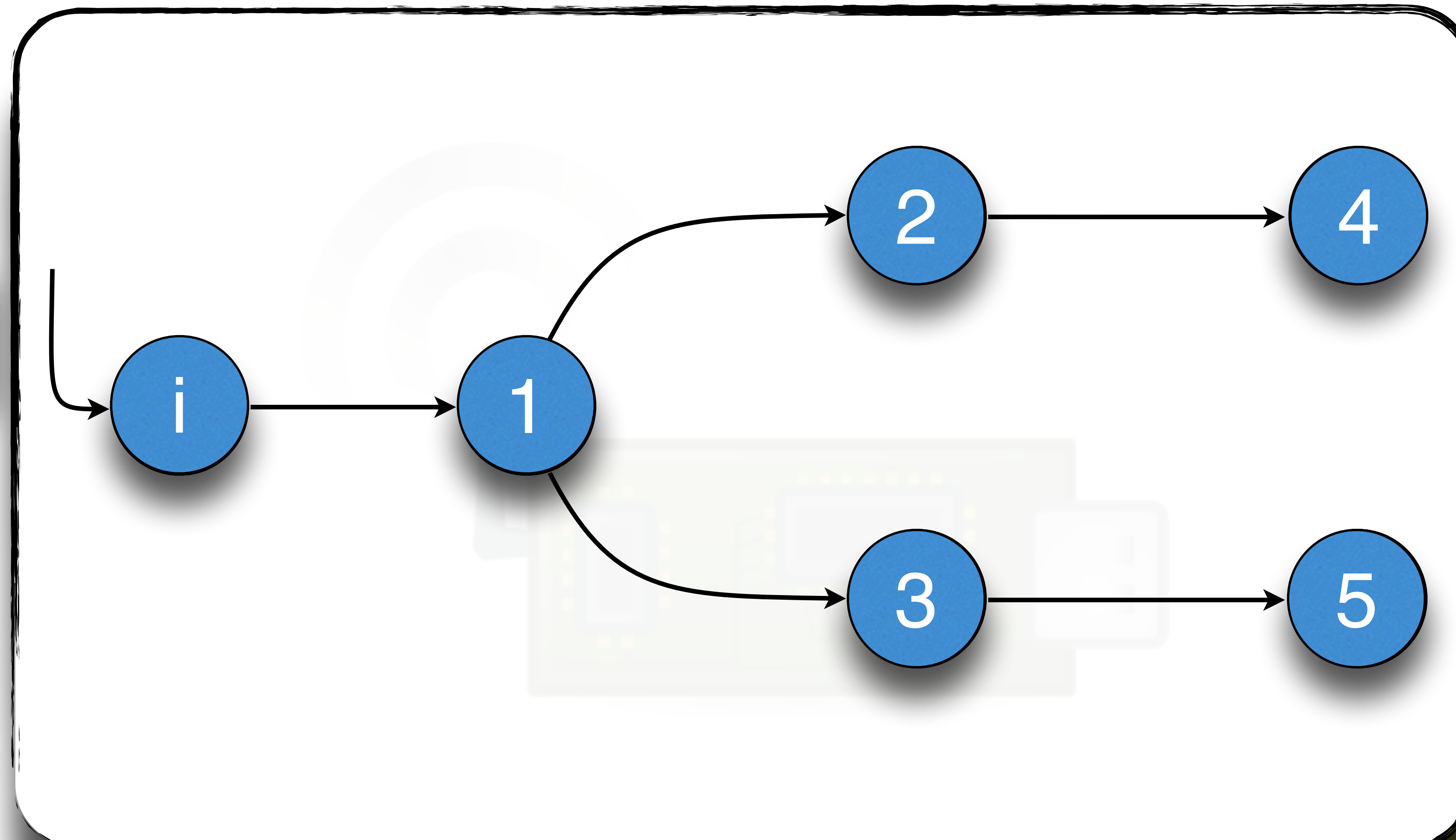

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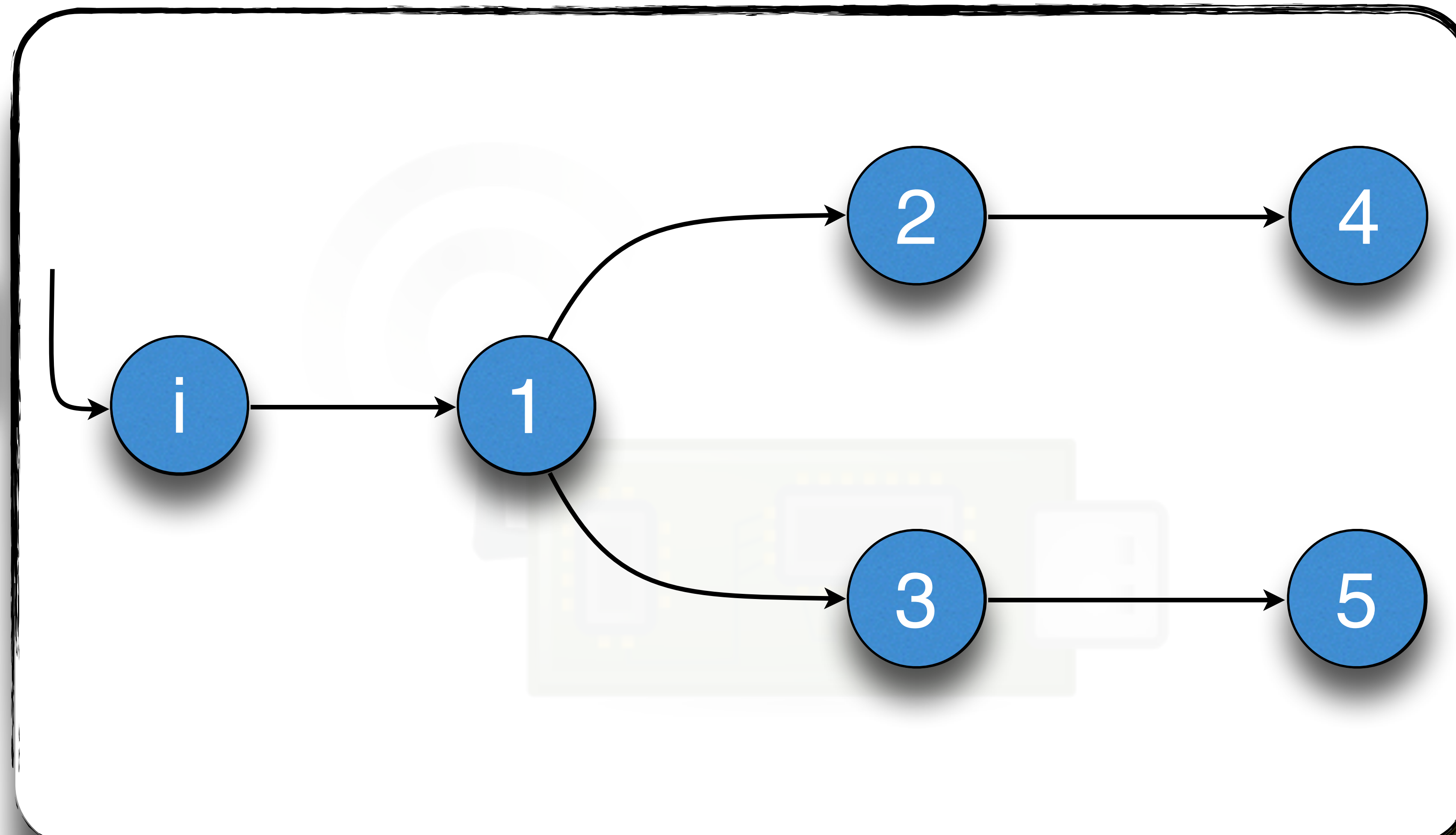
Model

Node:
Process

Transitions:



Direct

Ad-Hoc Networks

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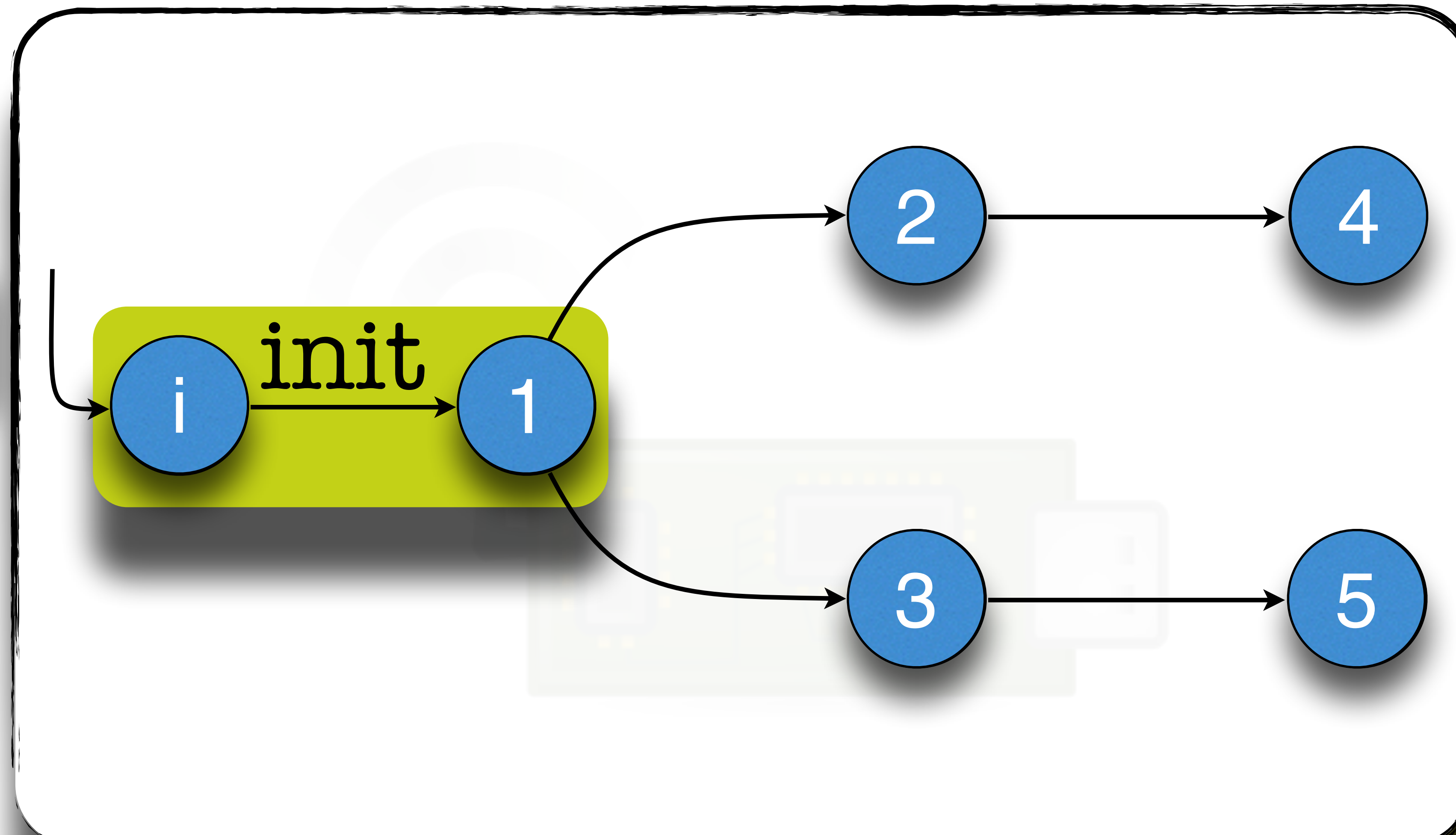
Model

Node:
Process

Transitions:

- Local



Direct

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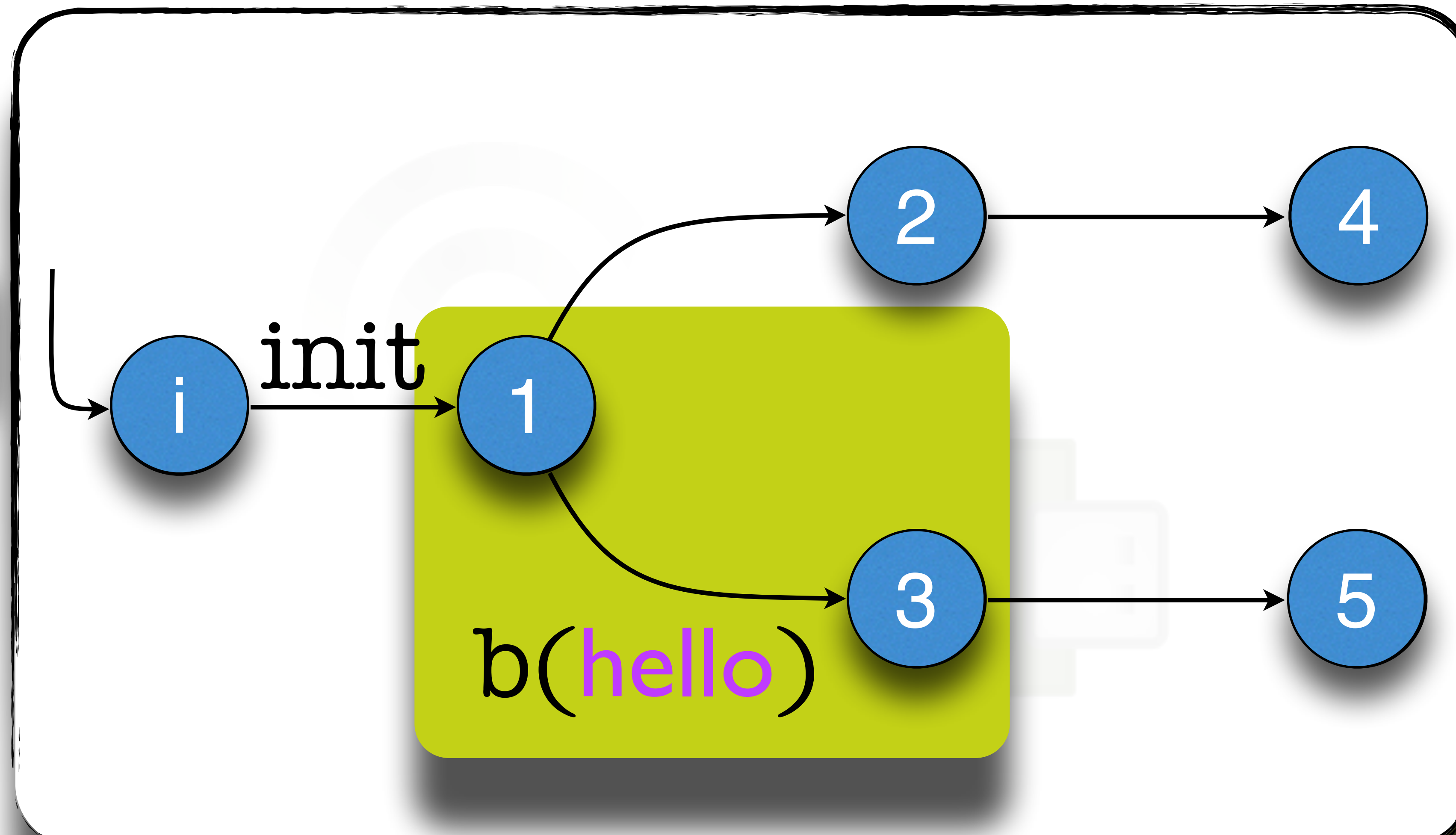
Model

Node:
Process

Transitions:

- Local
- Broadcast



Direct

Ad-Hoc Networks

- Model
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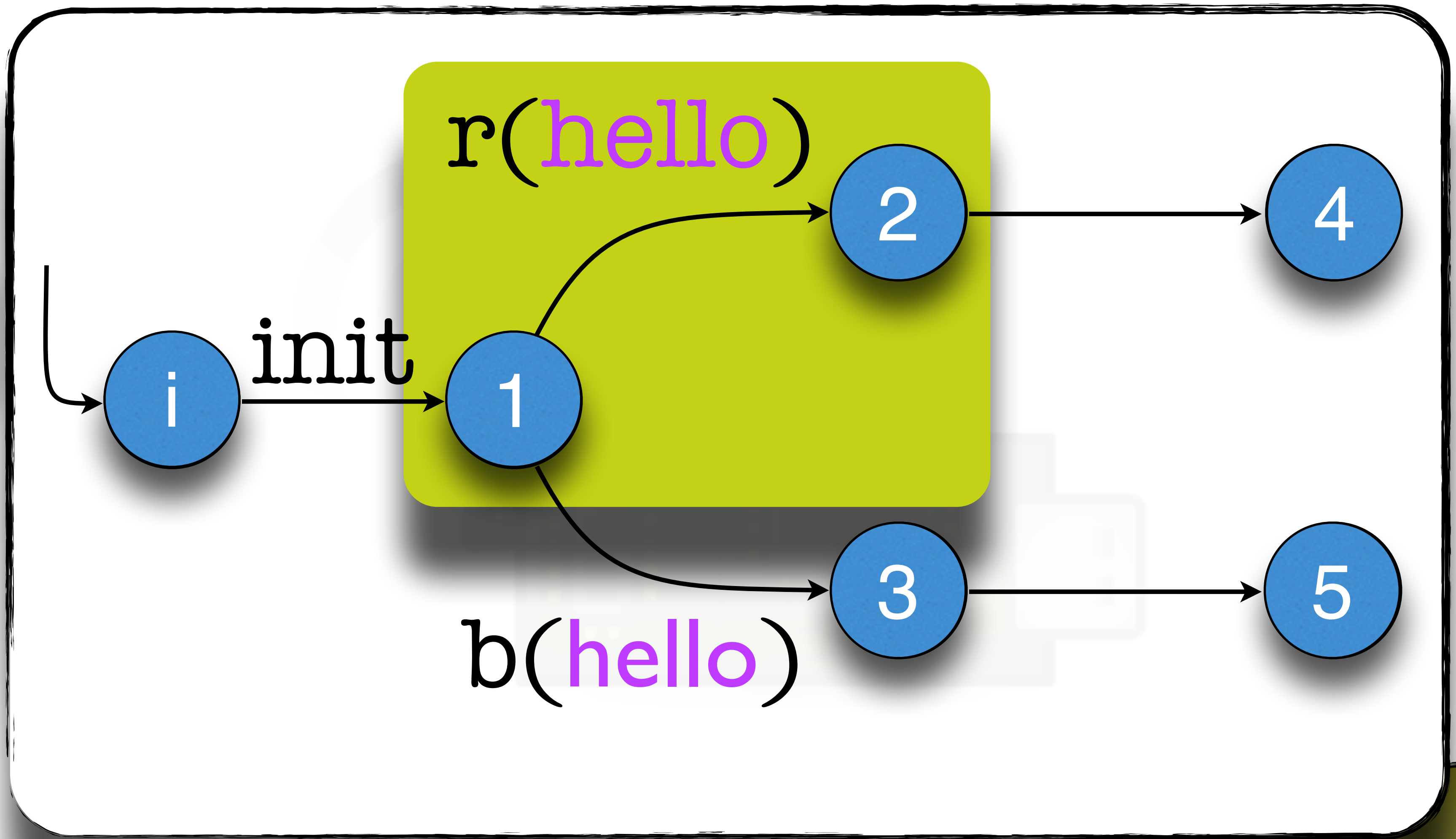
Model

Node:
Process

Transitions:

- Local
- Broadcast
- Receive



Direct

Broad

Ad-Hoc Networks

- Model
- Transition System
- Reachability

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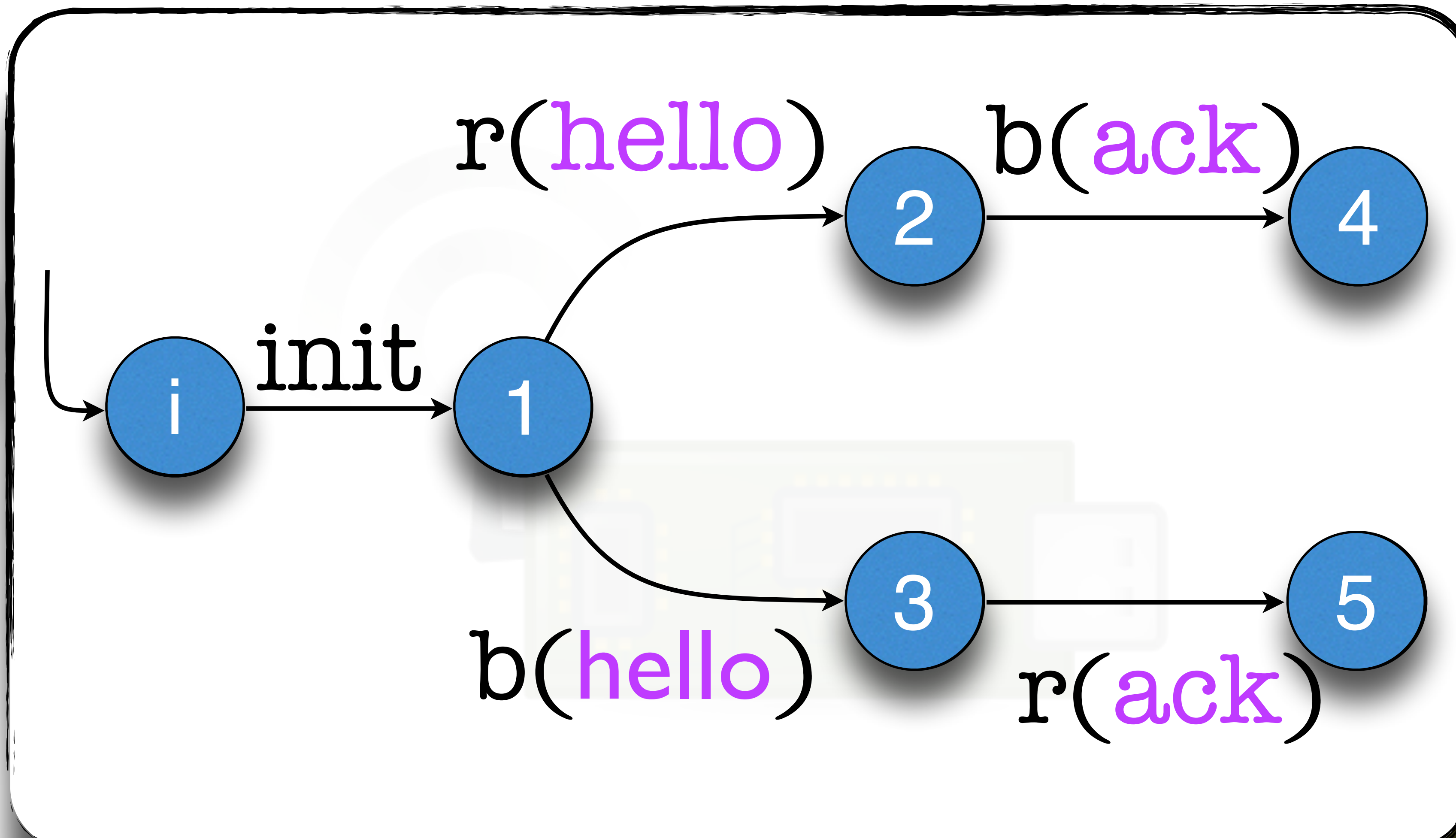
Parameterized verification of ad-hoc networks
CONCUR'10

Model

Node:
Process

Transitions:

- Local
- Broadcast
- Receive



Direct

Ad-Hoc Networks

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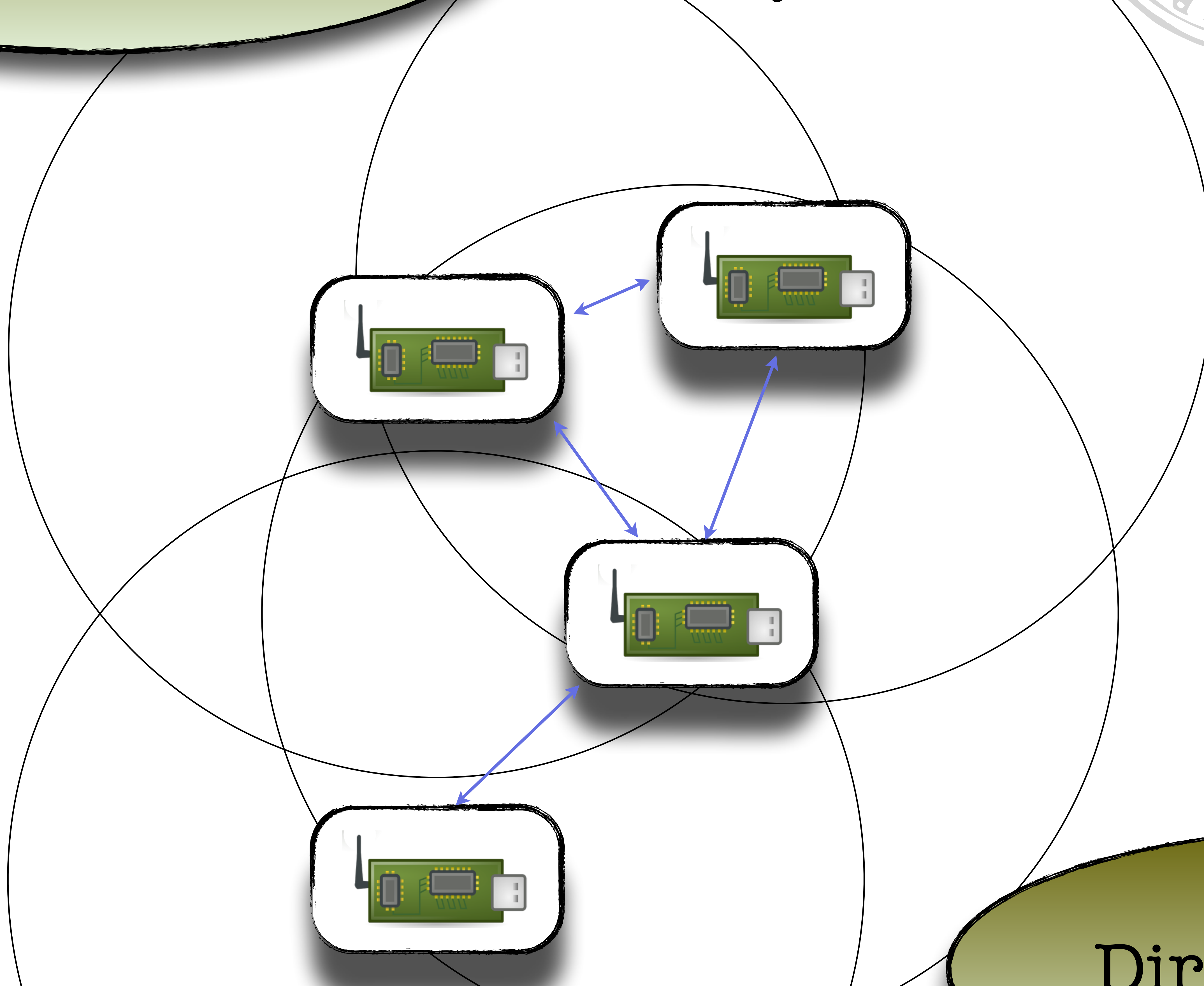

Direct

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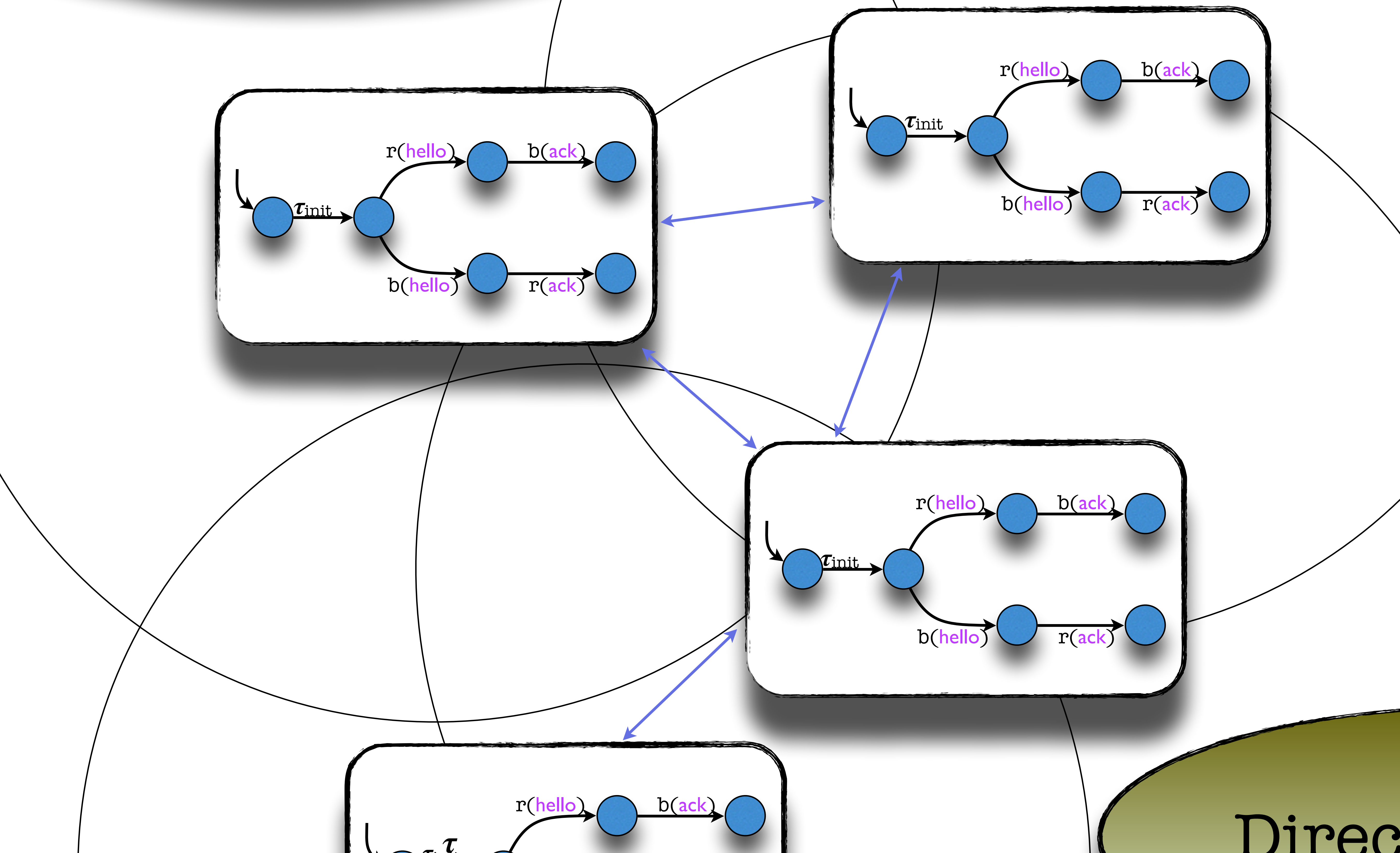

Direc

Ad-Hoc Networks

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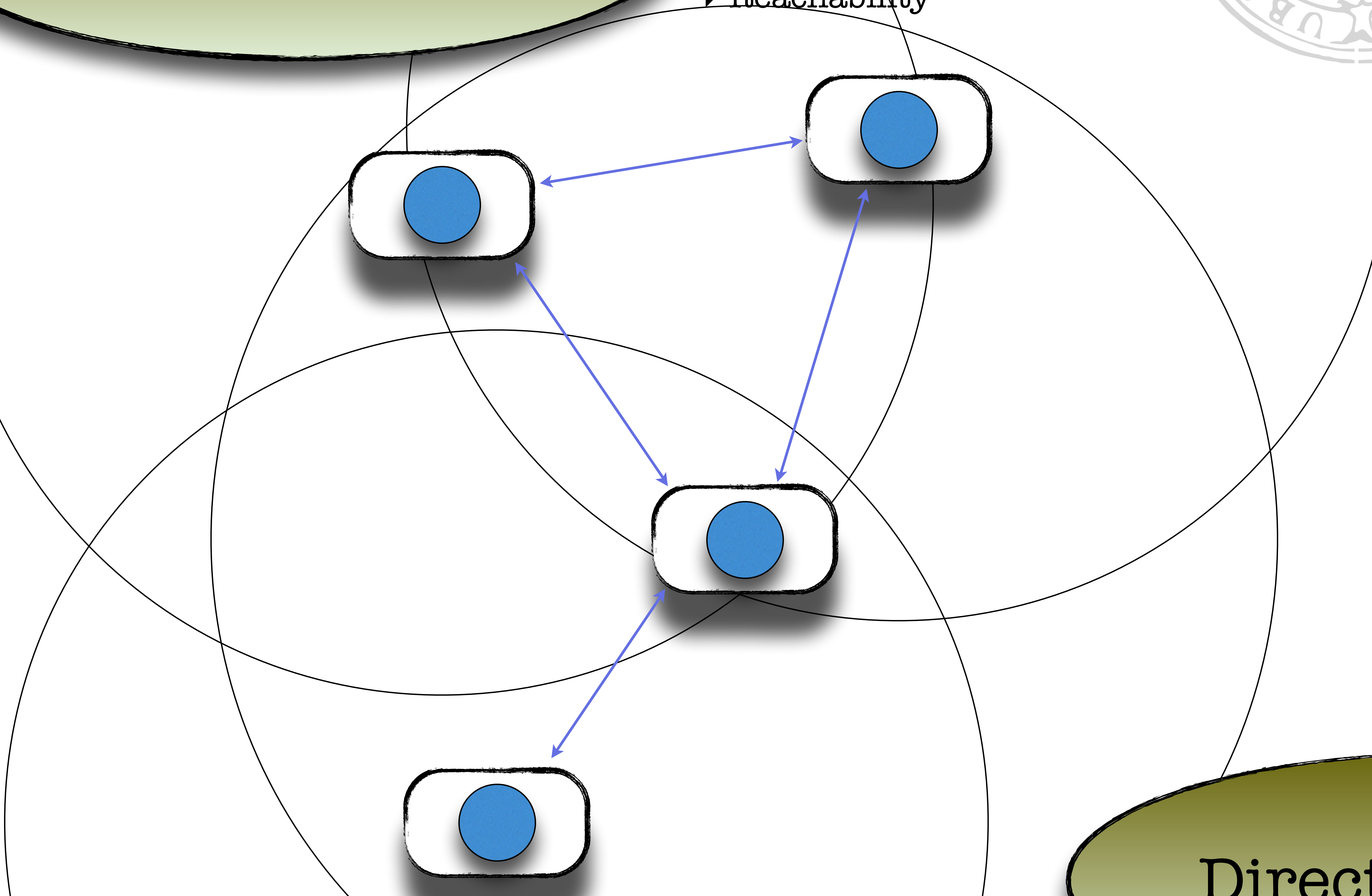

Direct

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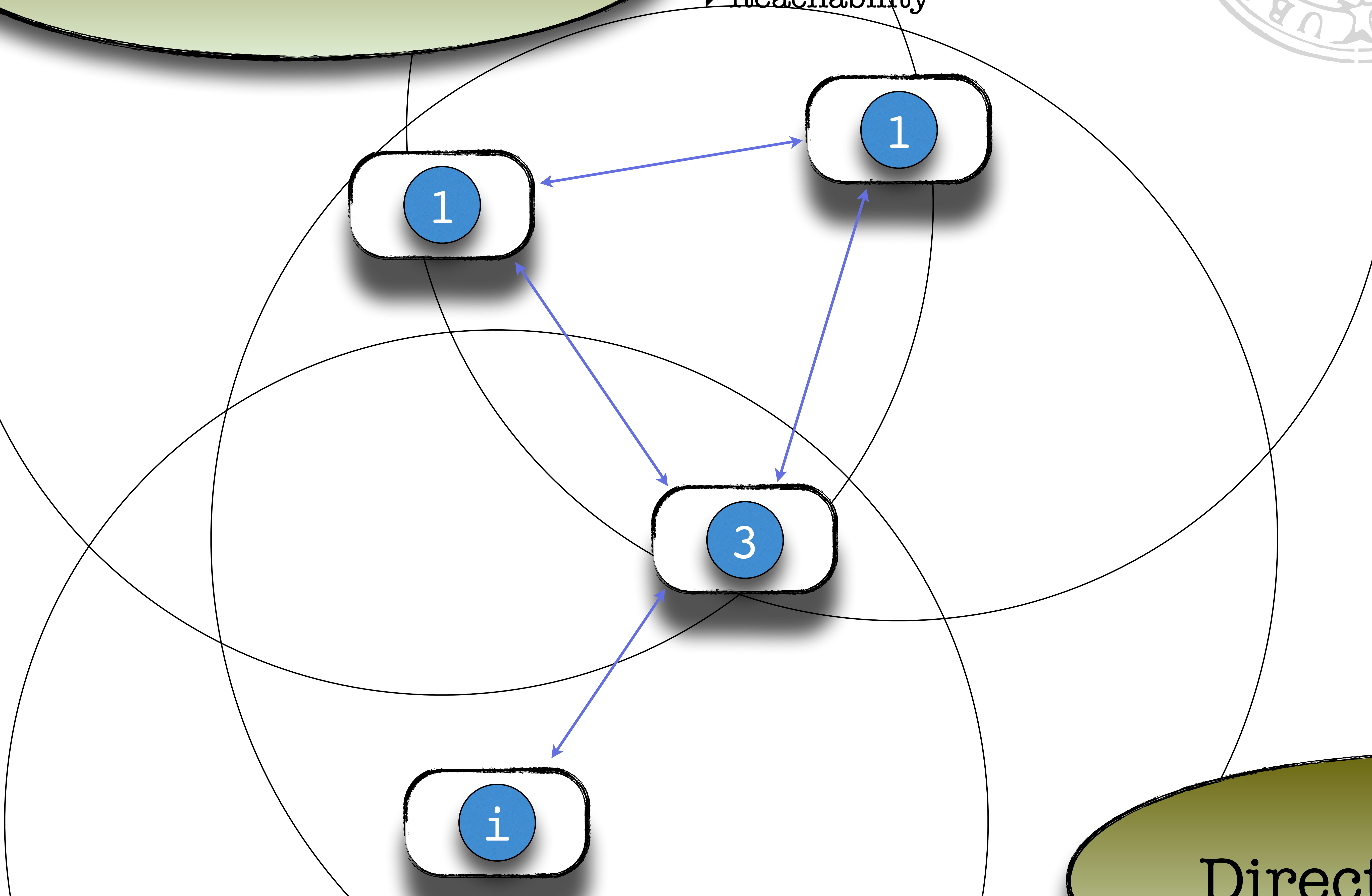

Direct

Ad-Hoc Networks

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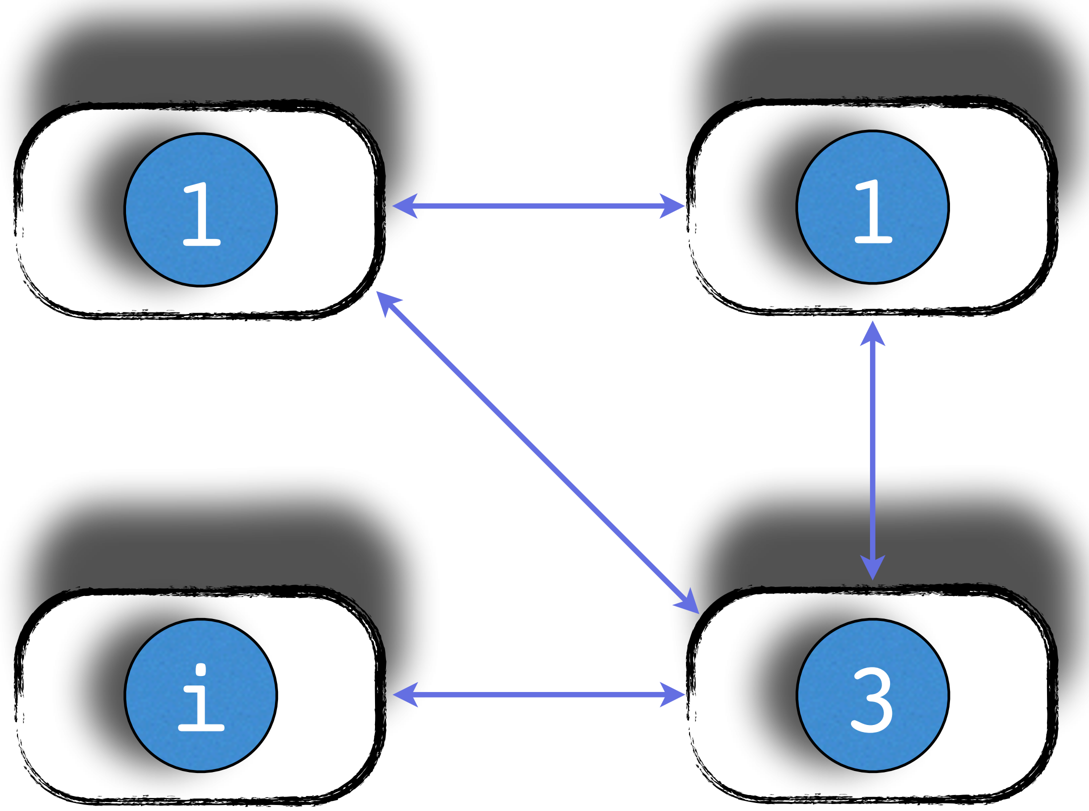
Model

Node:
Process



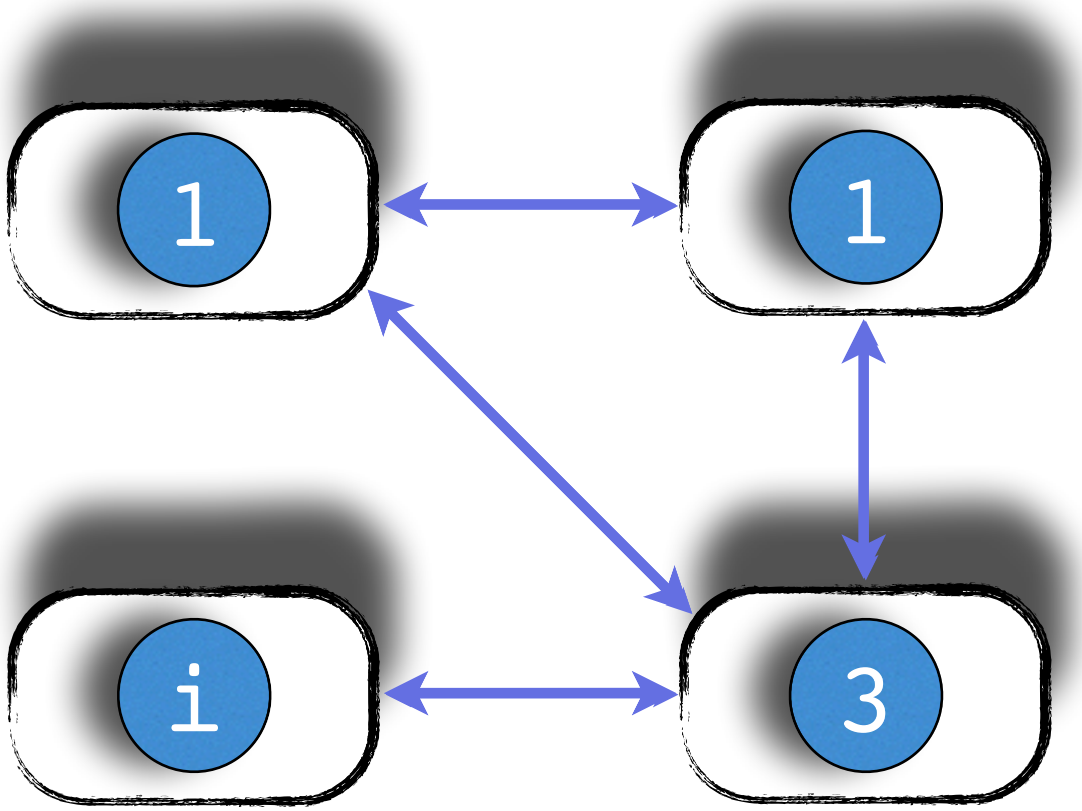
Direct

Ad-Hoc Networks

Model

Node:
Process

Topology:
Symmetric graph



Direct

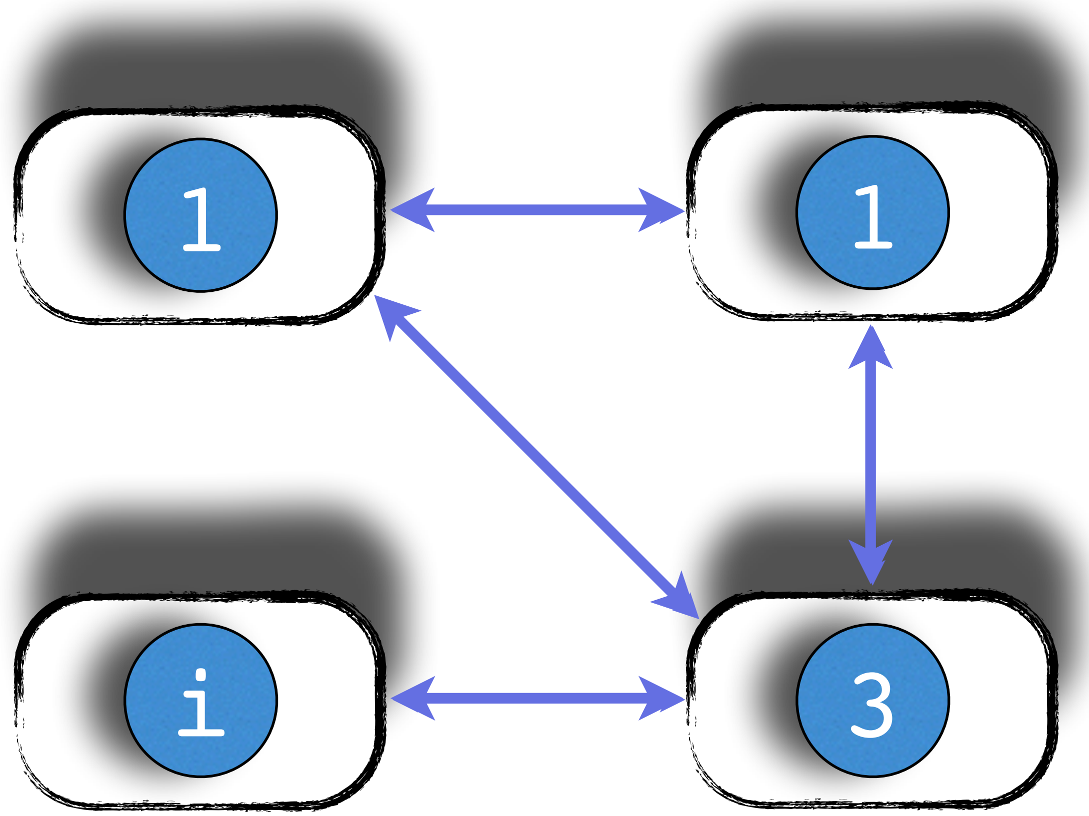
Ad-Hoc Networks

Model

Node:
Process

Topology:
Symmetric graph

Configuration:
Graph, state mapping



Direct

Ad-Hoc Networks

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$$< \Gamma, \longrightarrow >$$

Direct

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Ad-Hoc Networks

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$$< \Gamma, \longrightarrow >$$

- Set of configurations
- Transition Relation
- Trace

Direct

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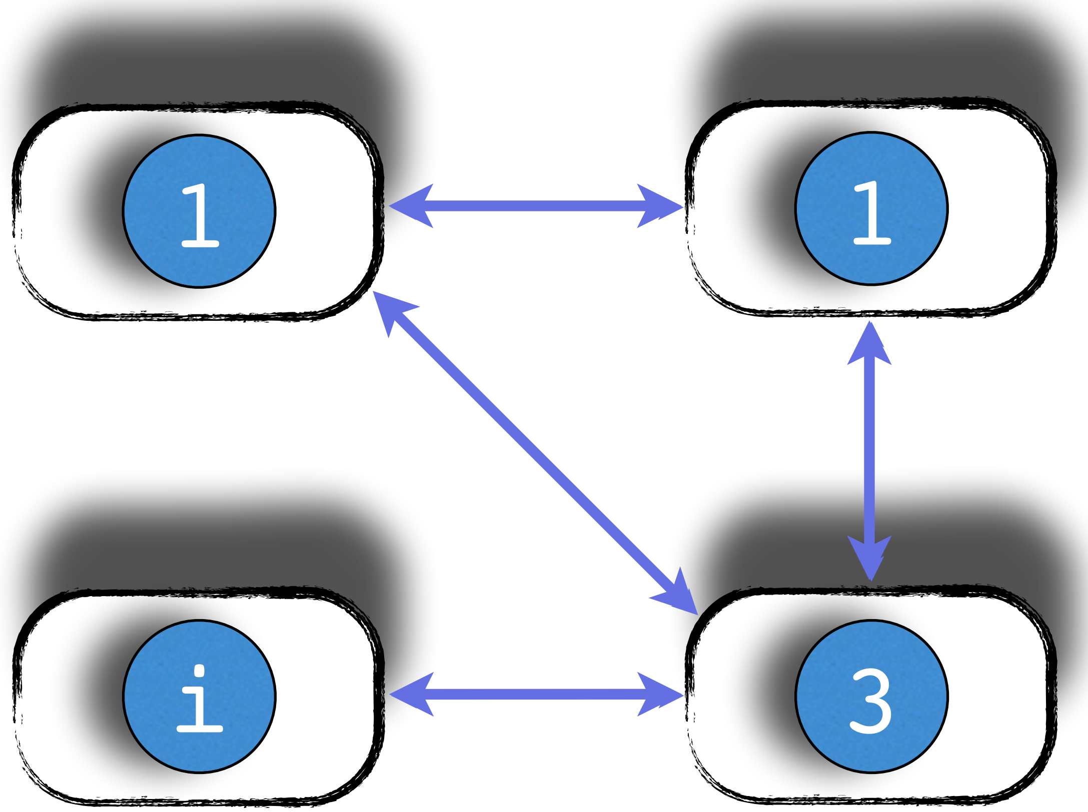

Direct

Ad-Hoc Networks

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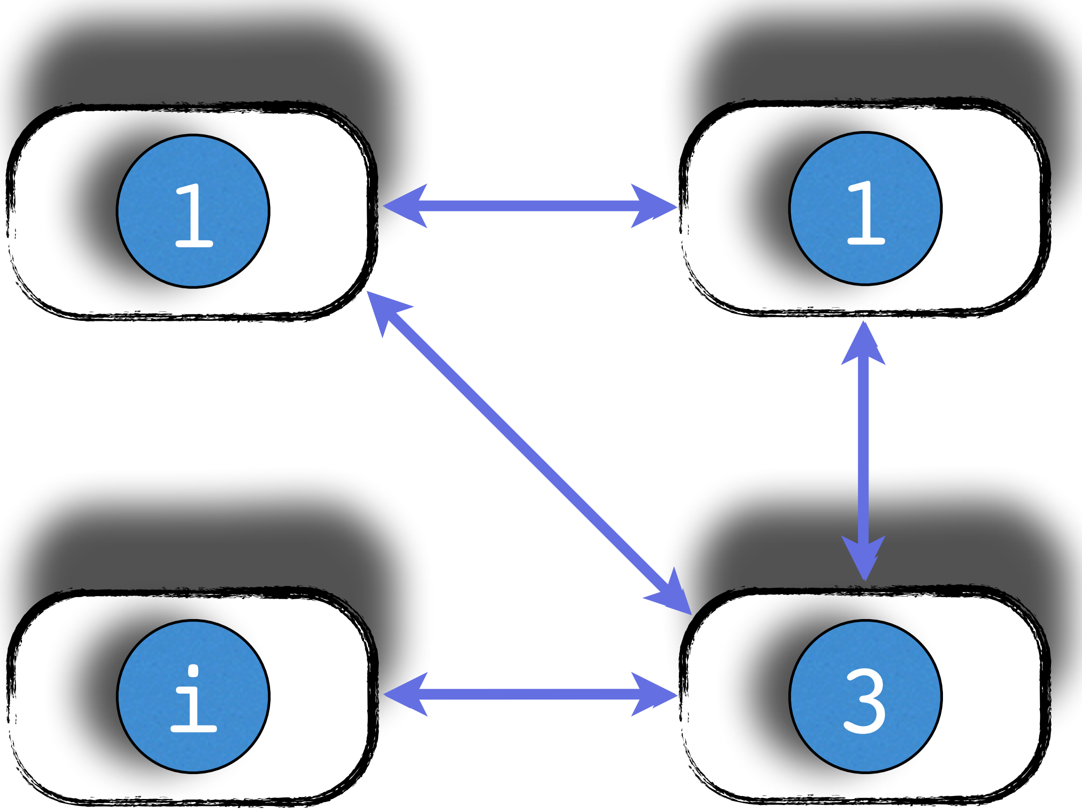

- Any Symmetric Graph

Direct

Ad-Hoc Networks

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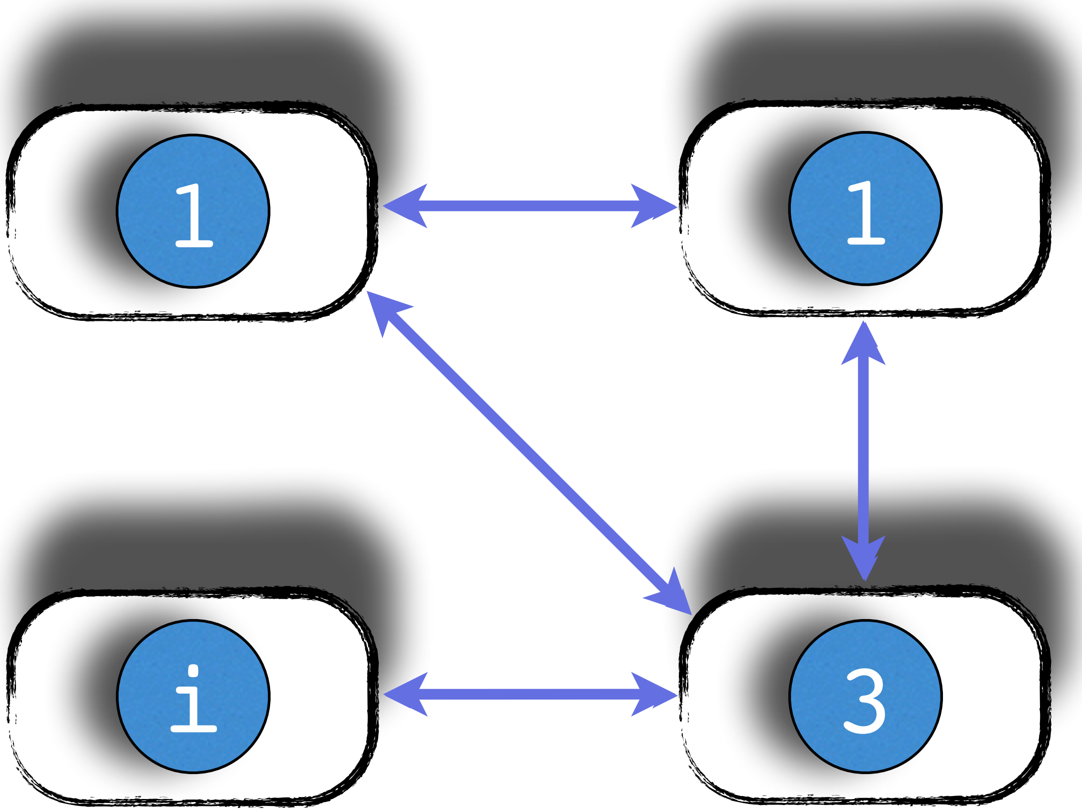

- Any Symmetric Graph
- Unbounded # of nodes

Direct

Ad-Hoc Networks

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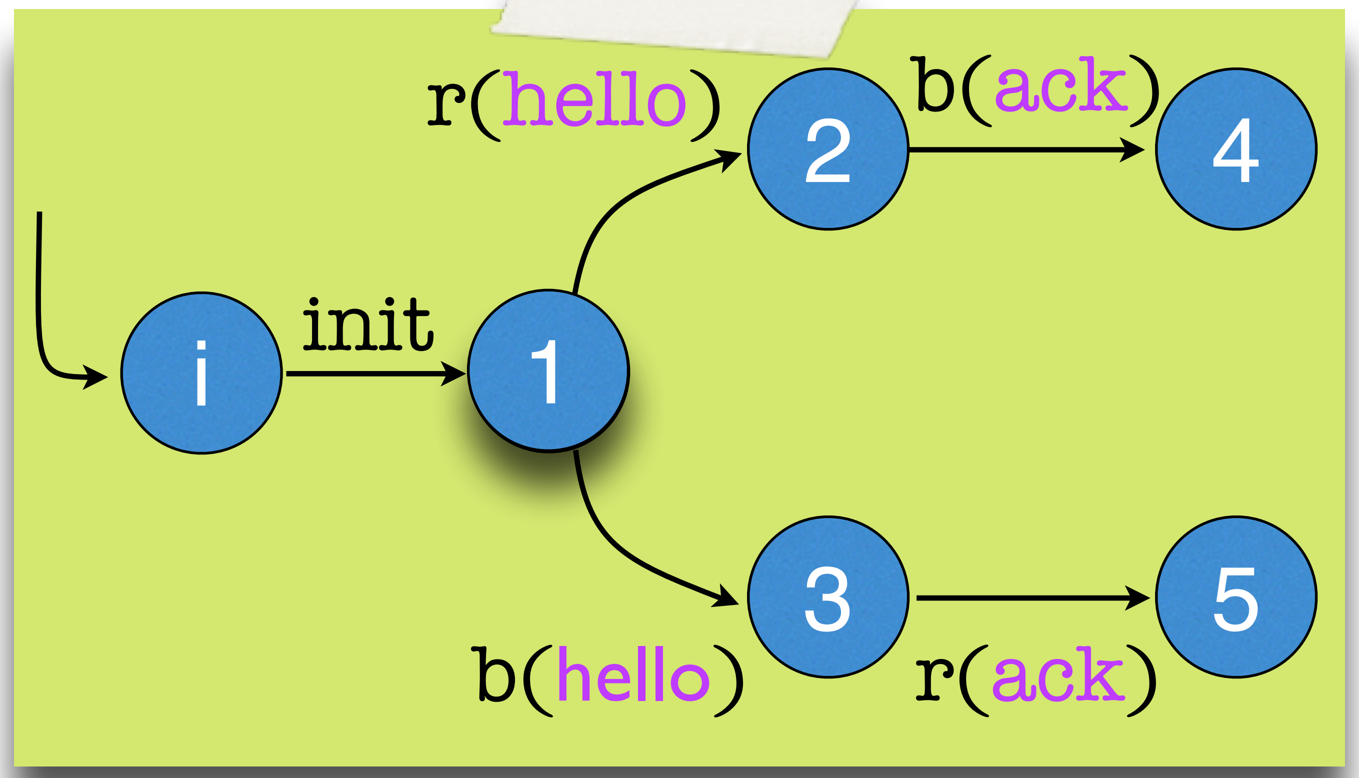
Process



Direct

Ad-Hoc Networks

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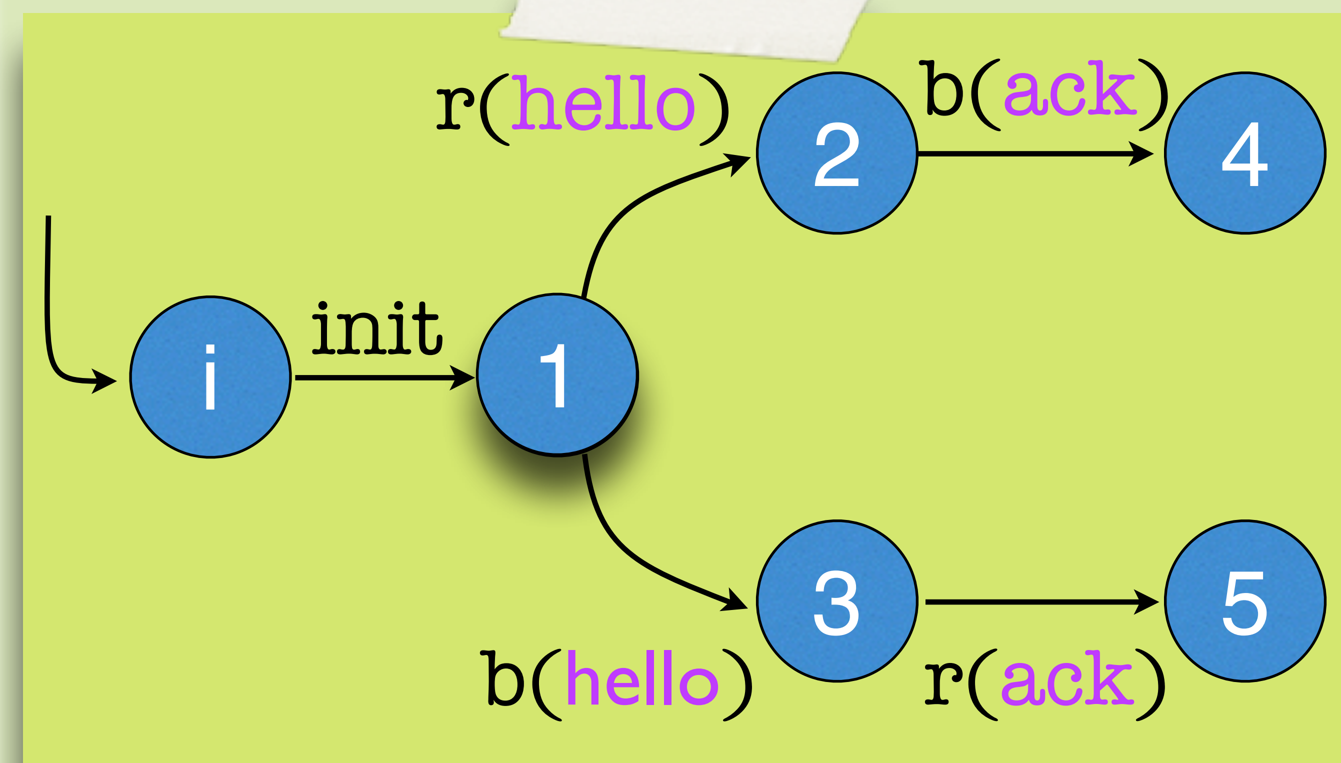
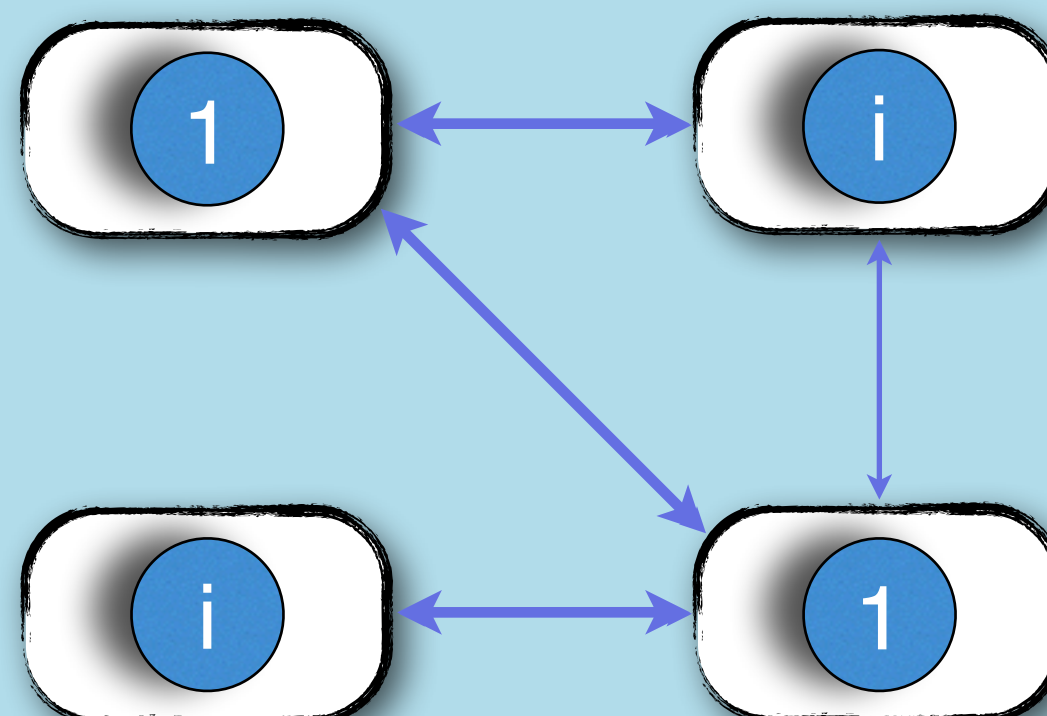
$$< \Gamma, \longrightarrow >$$

- Set of configurations
- **Transition Relation**
- Trace

Process



Configuration



Direct

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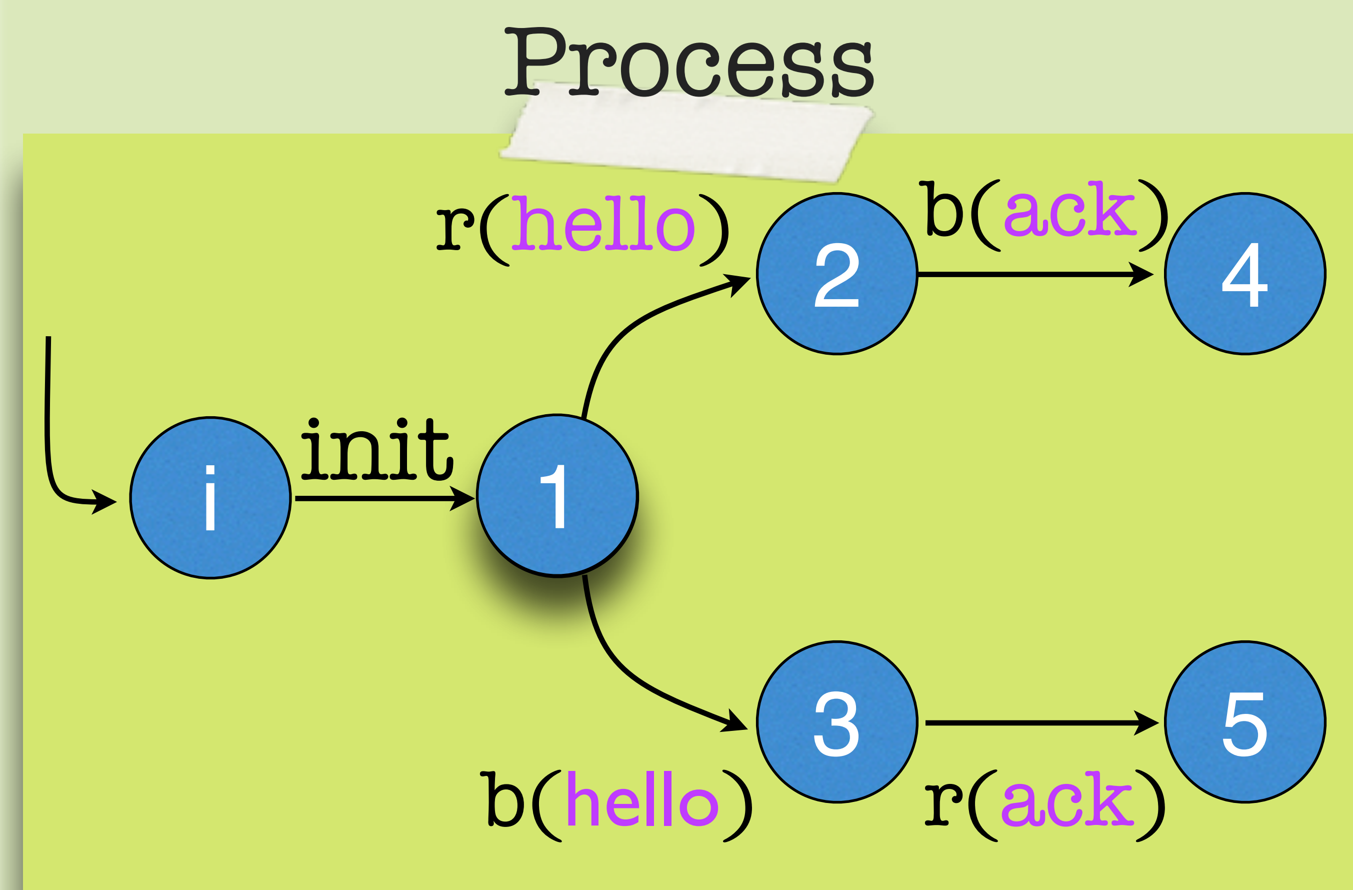
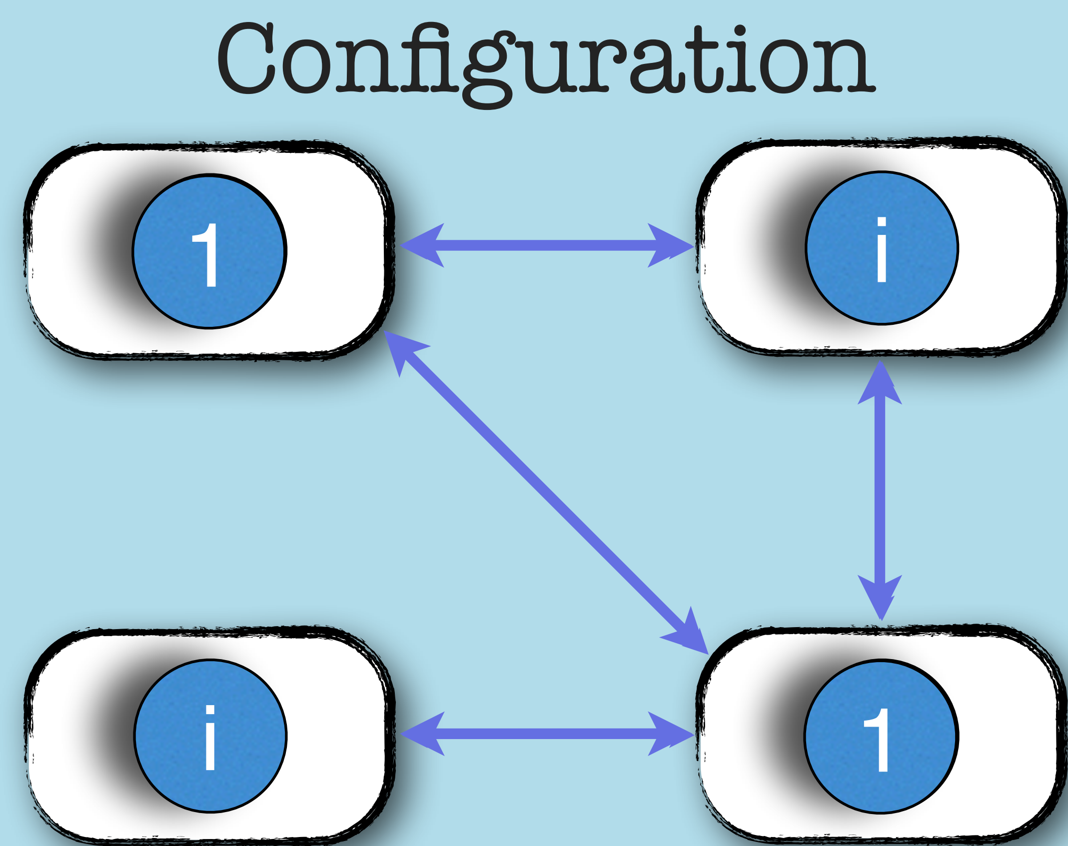


- local



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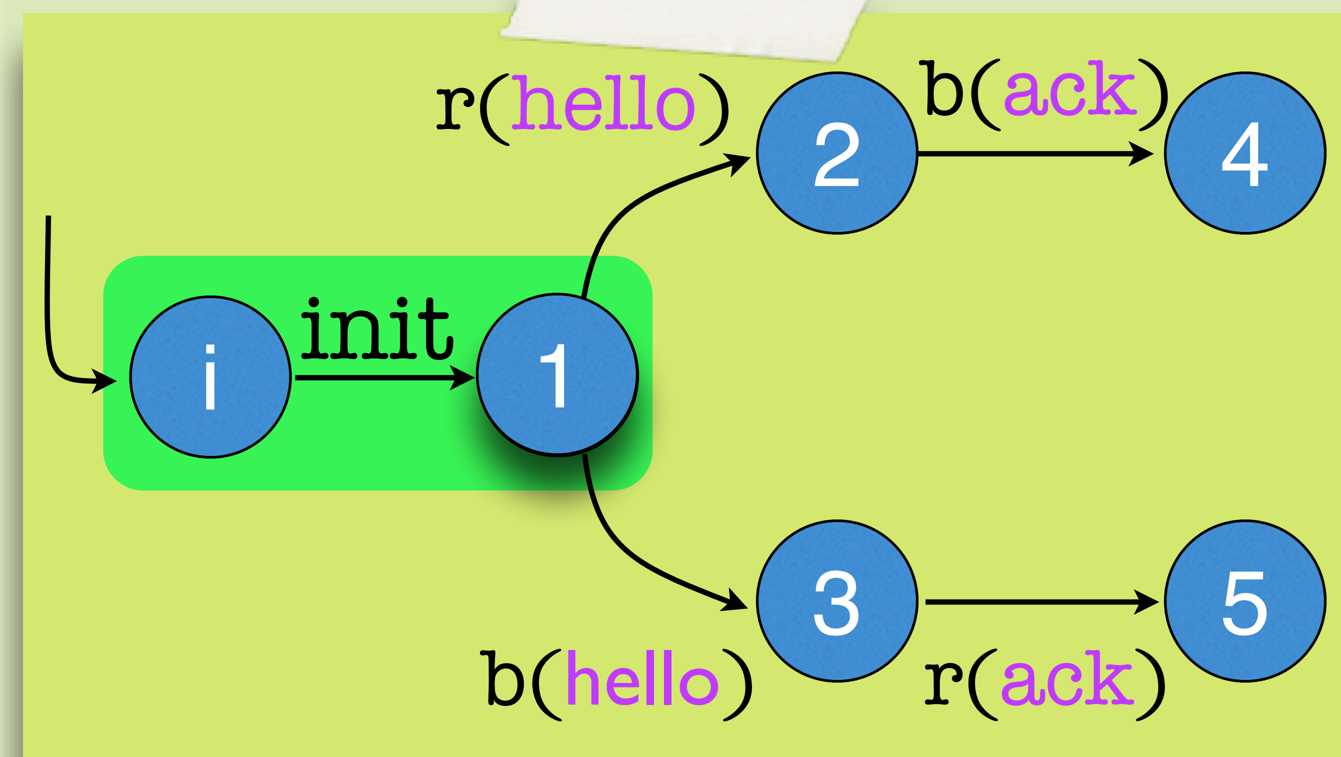

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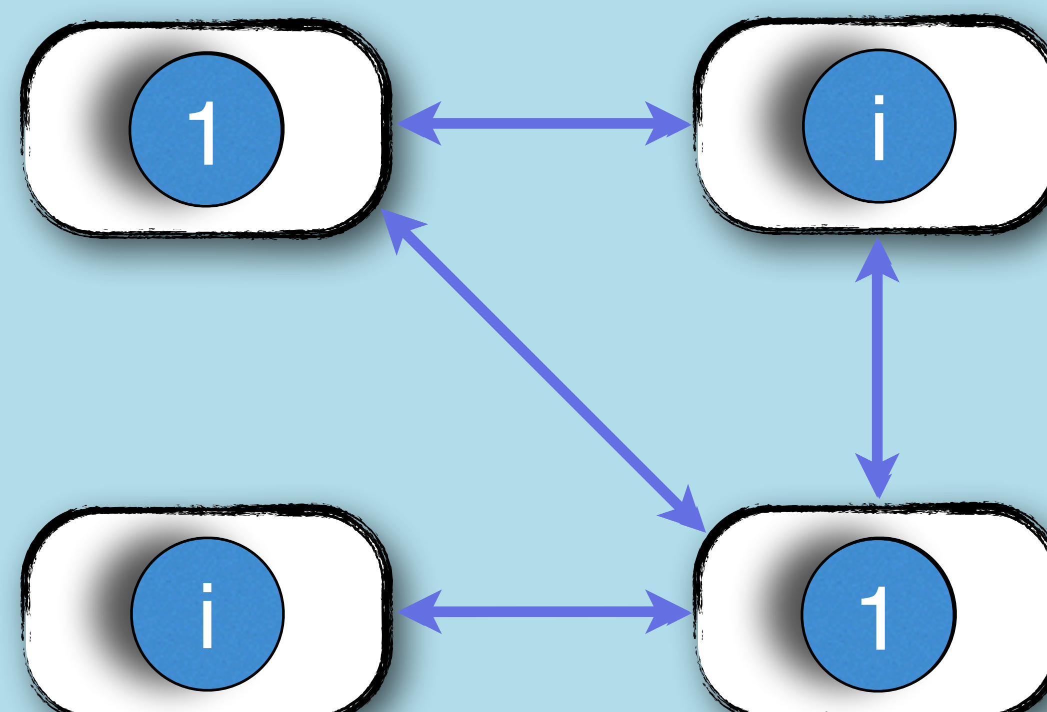
Configuration



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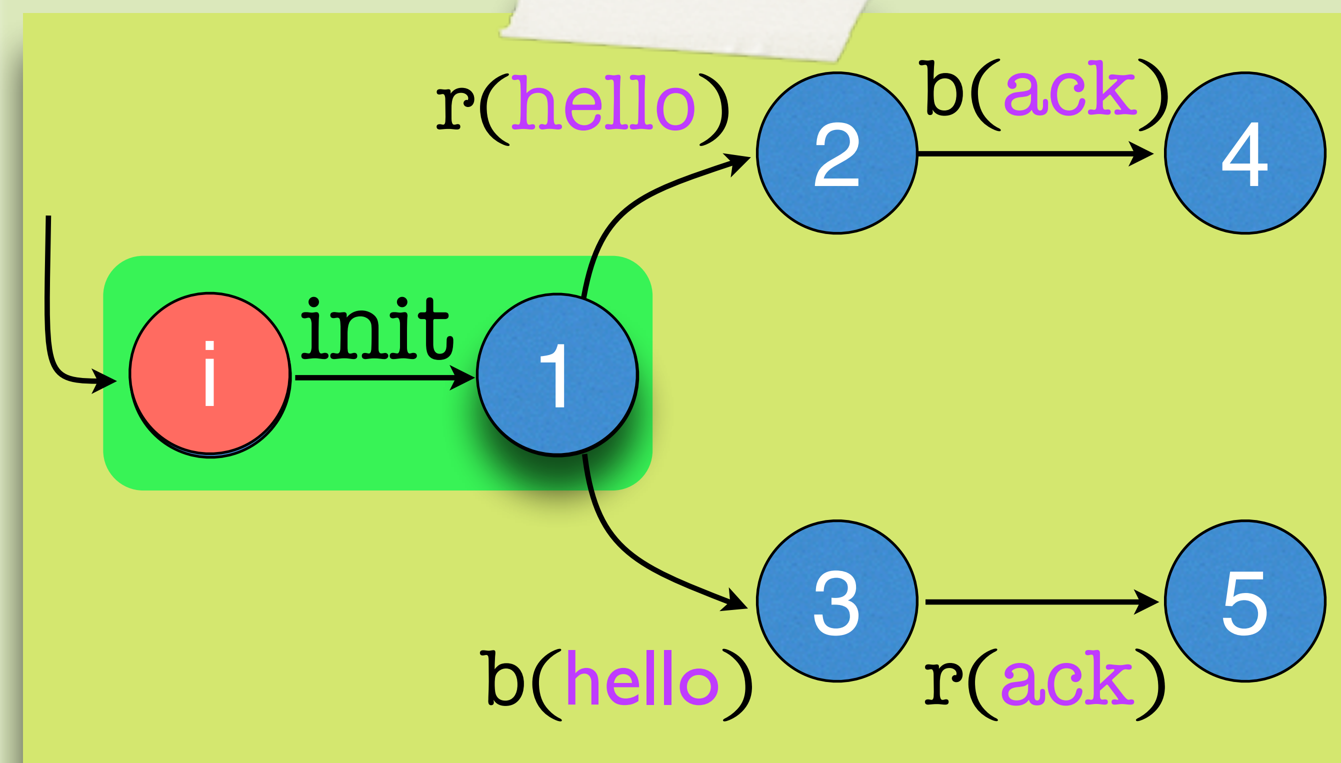

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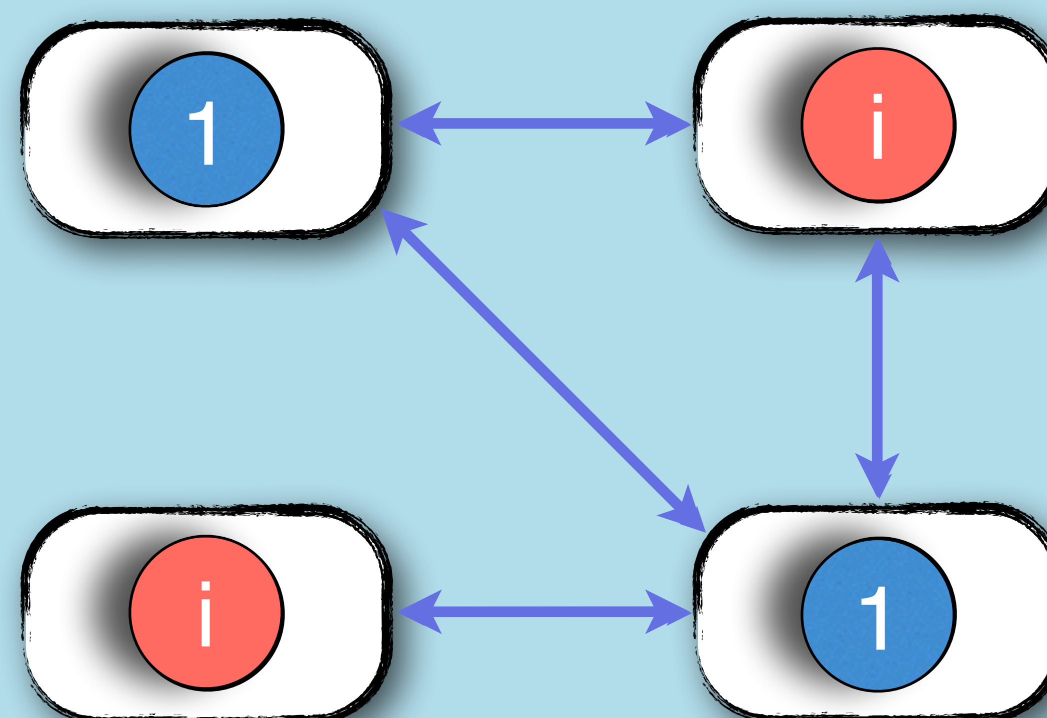

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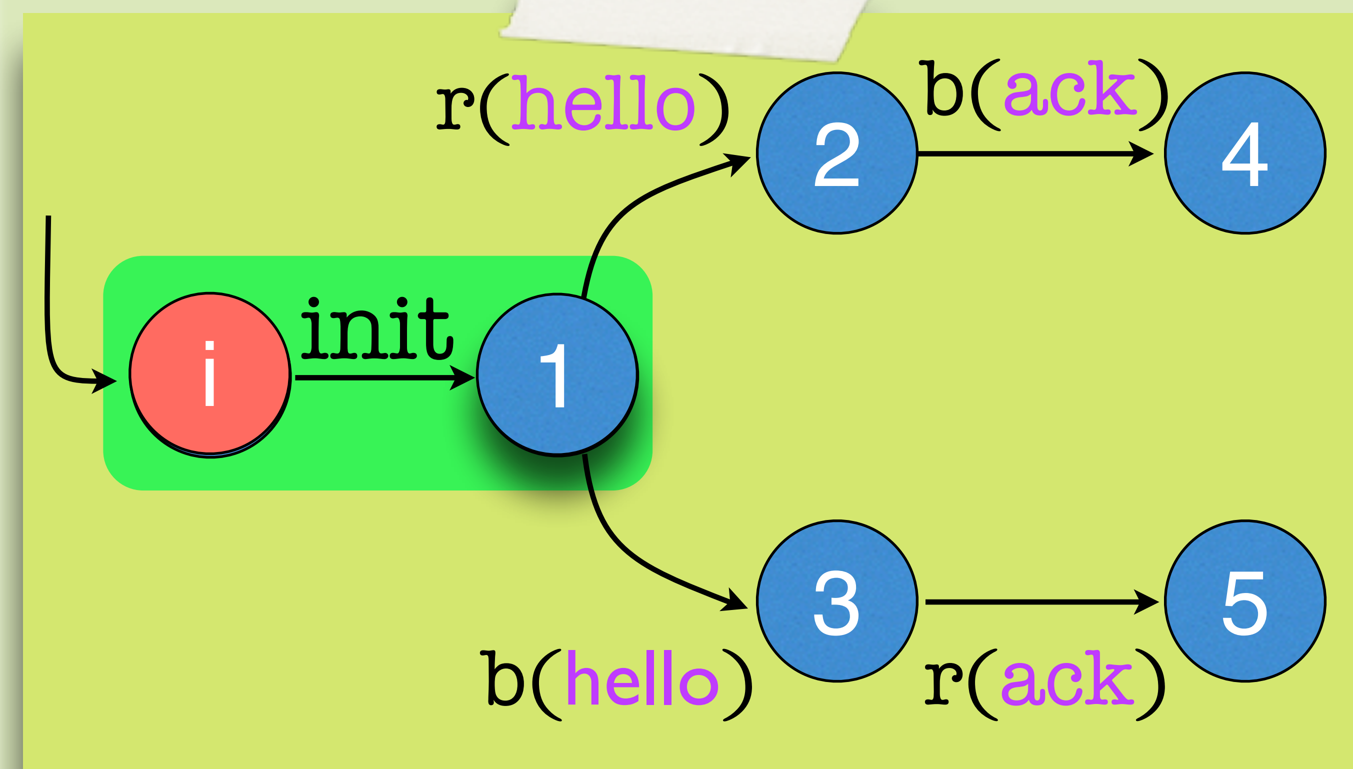

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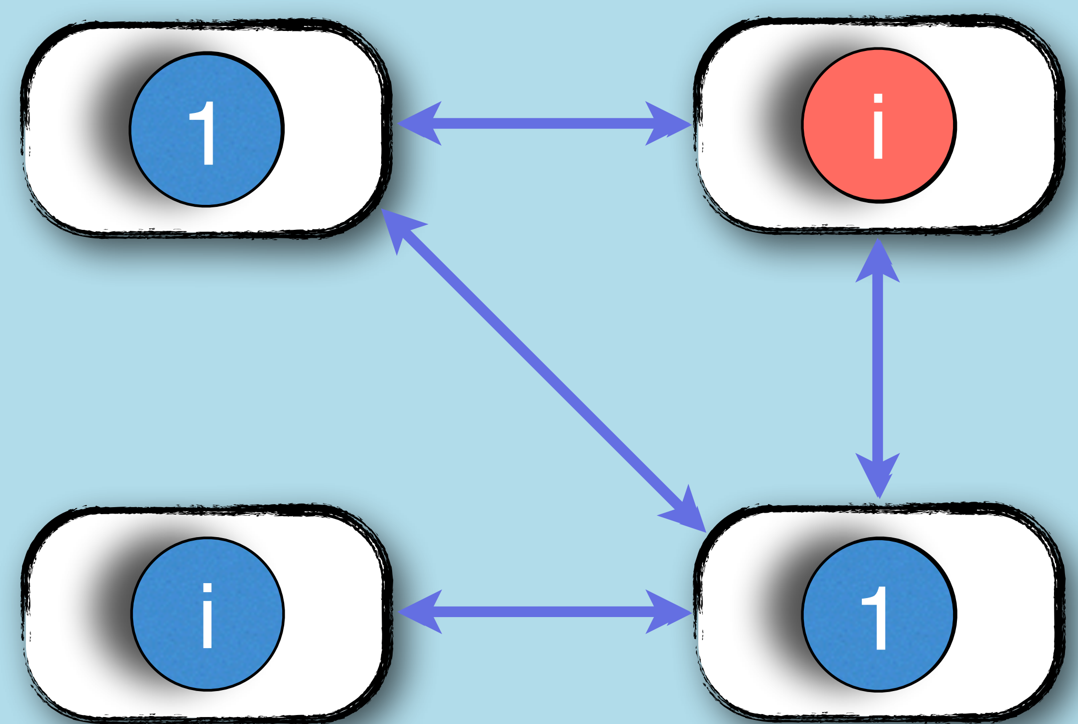
Configuration



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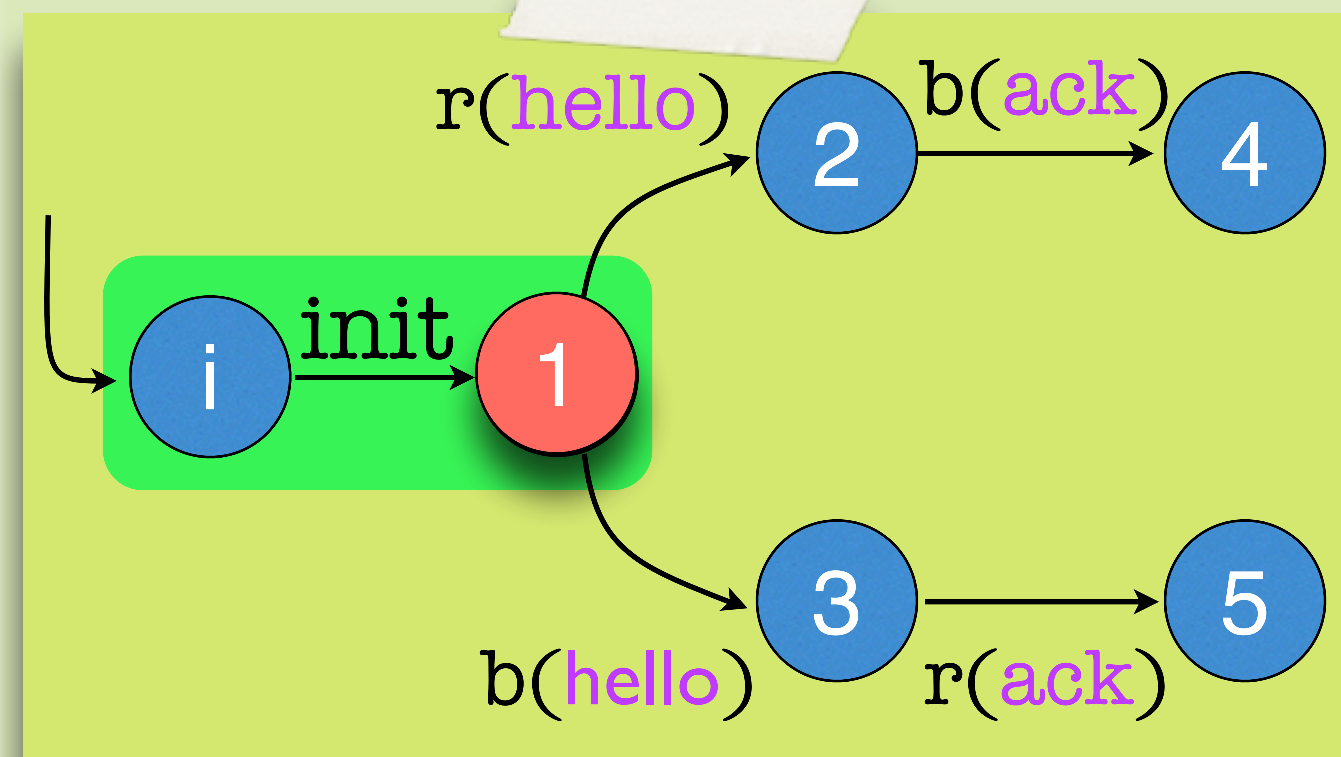
Process



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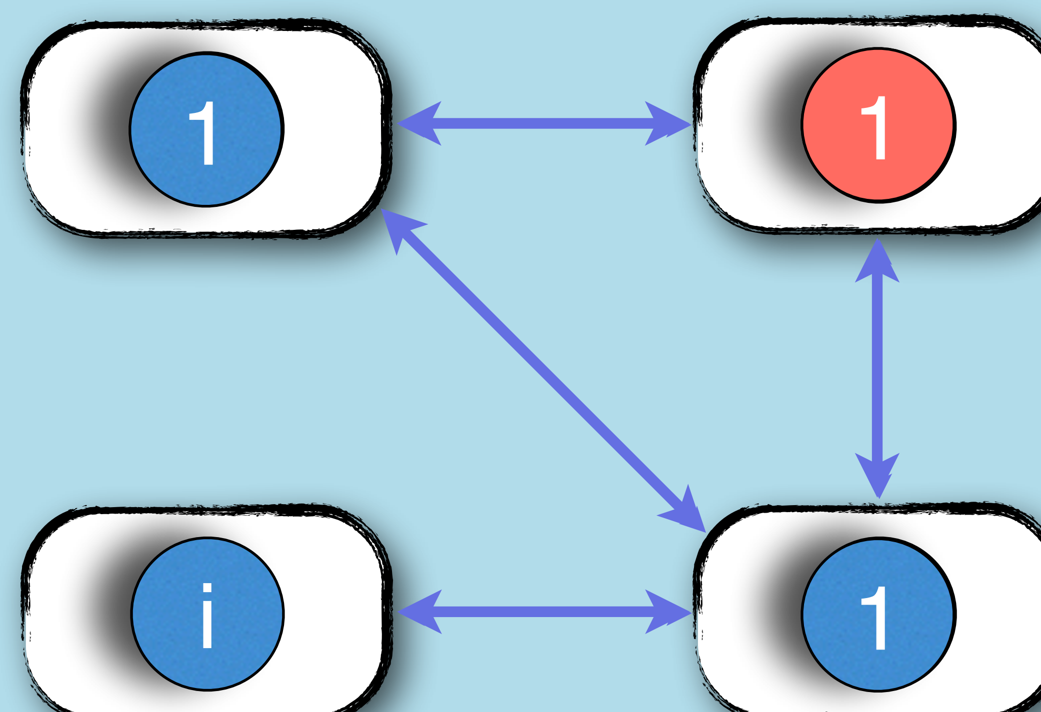
Configuration



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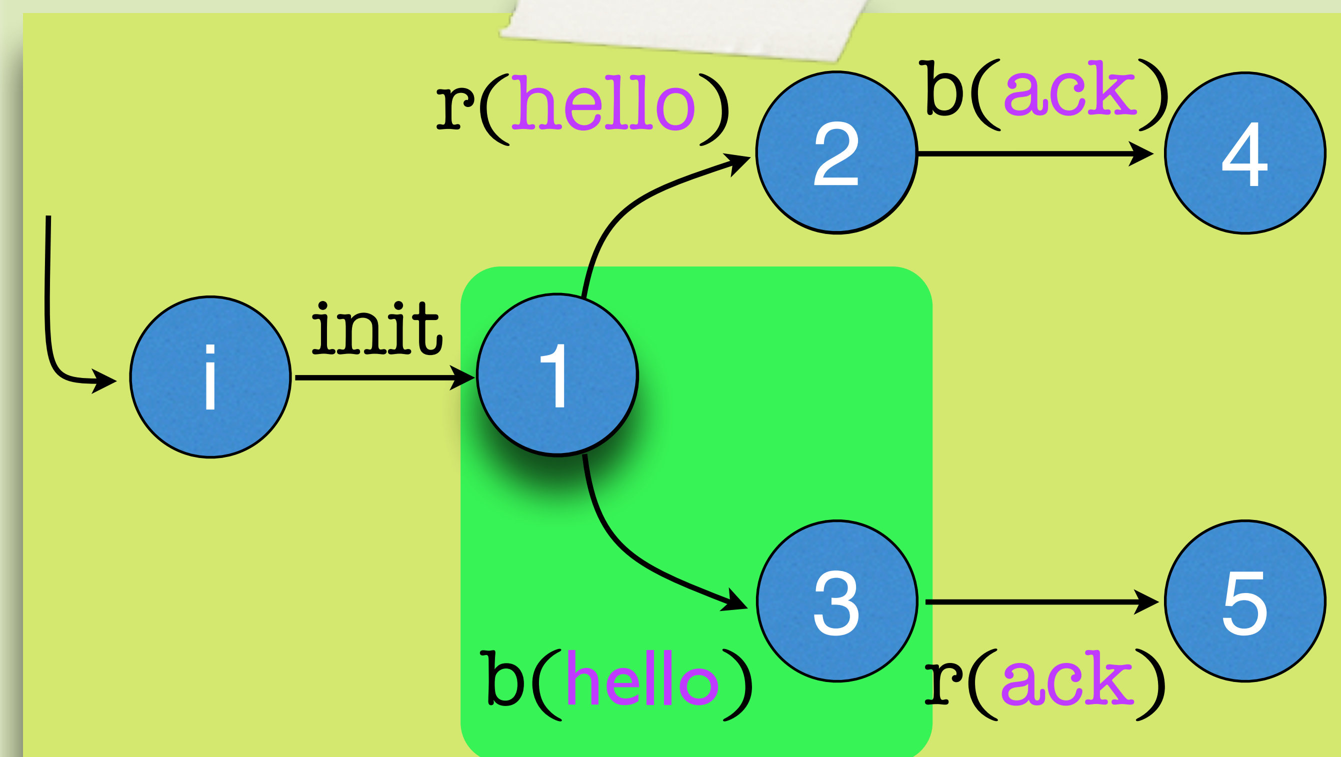
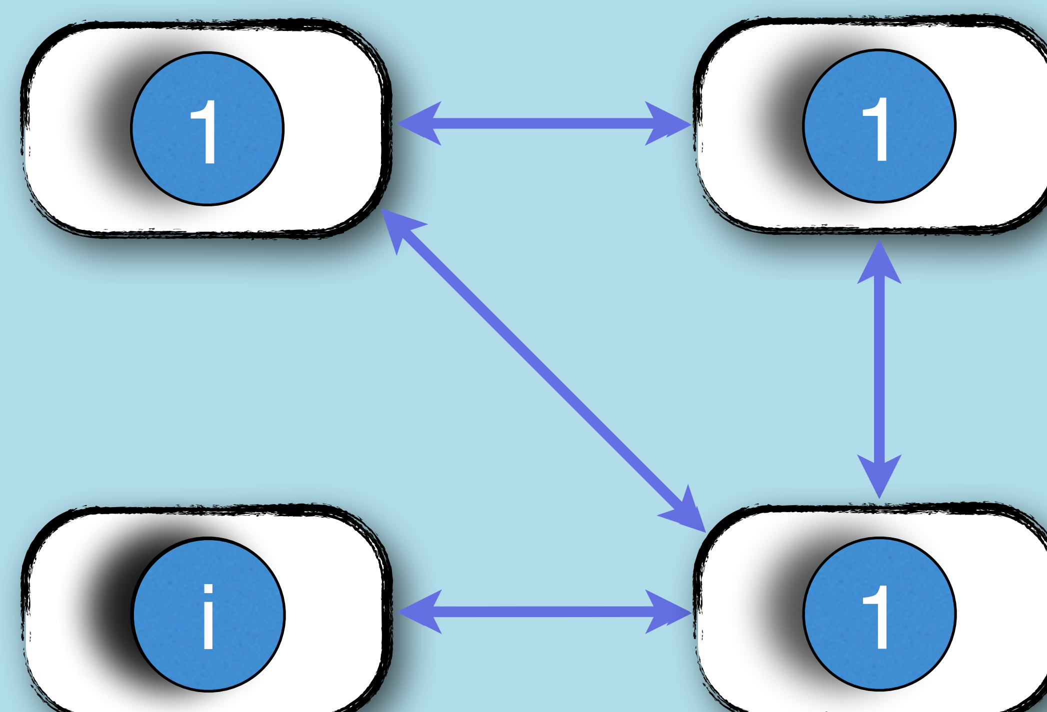
Process



- local
- broadcast
- receive

Configuration



- local
- selective broadcast

Direct

Ad-Hoc Networks

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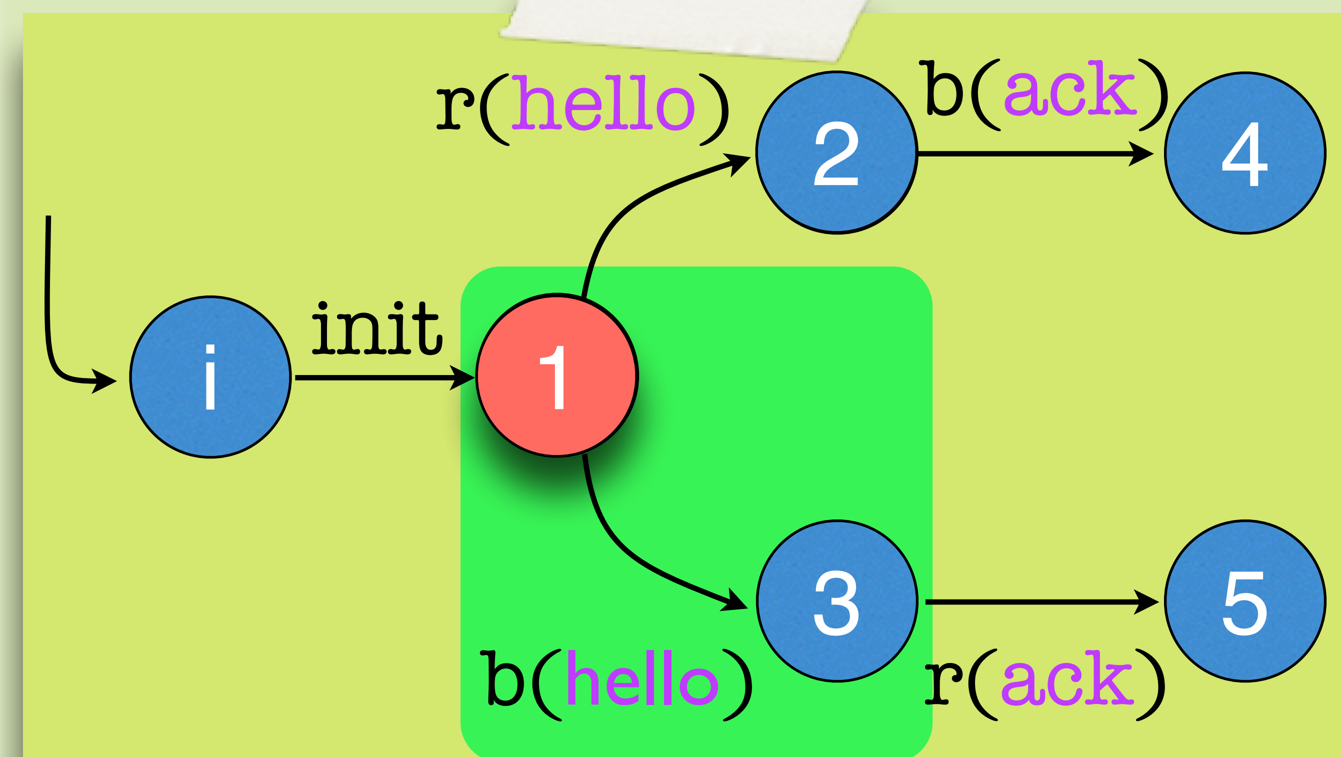
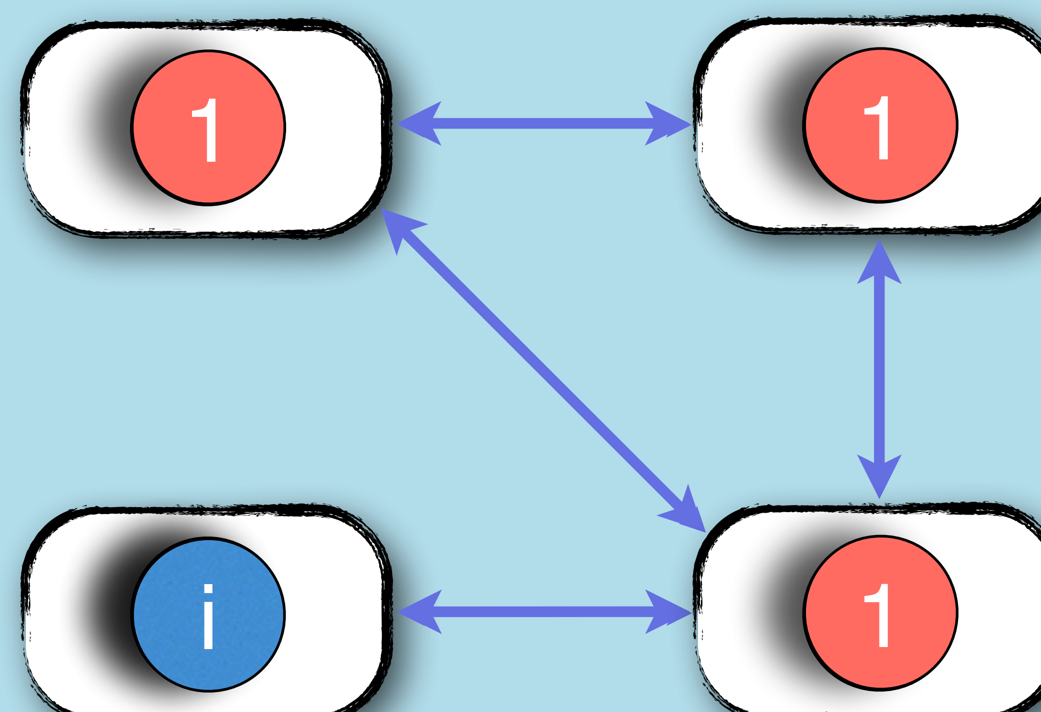
$$< \Gamma, \longrightarrow >$$

Process



- local
- broadcast
- receive

Configuration



- local
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Direct

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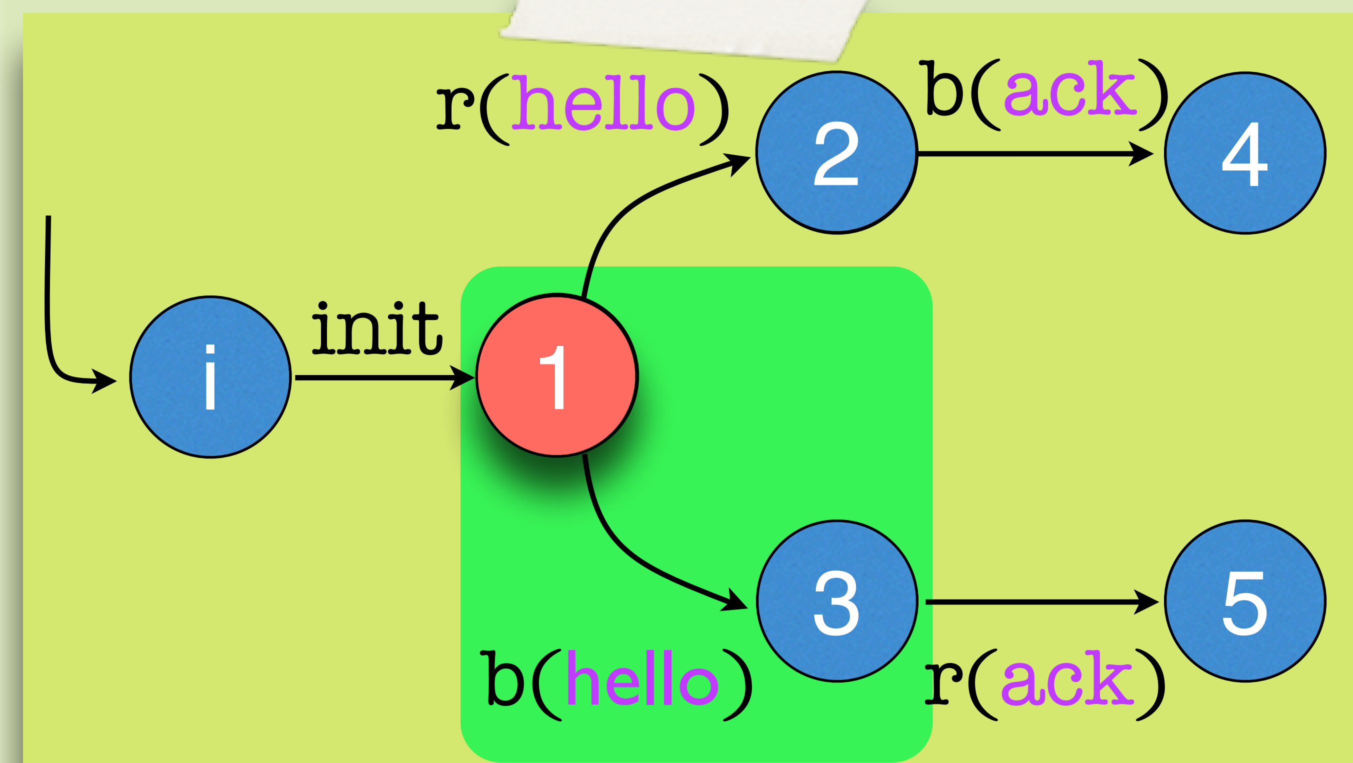
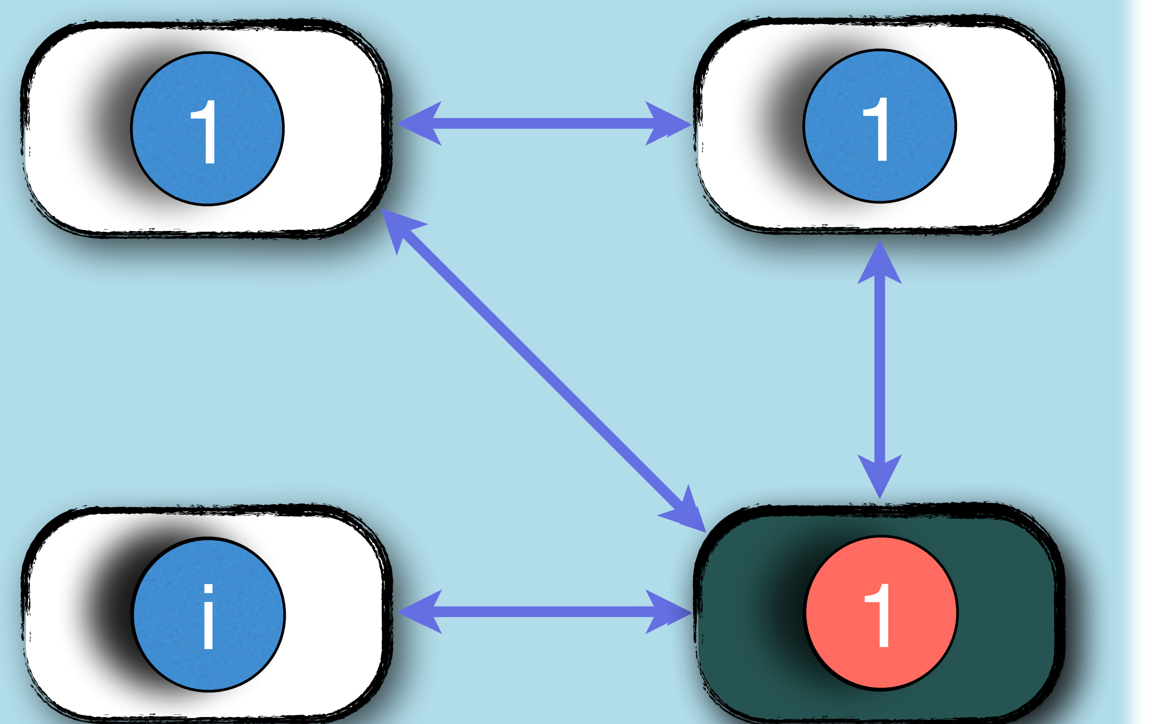


- local
- broadcast
- receive

Configuration



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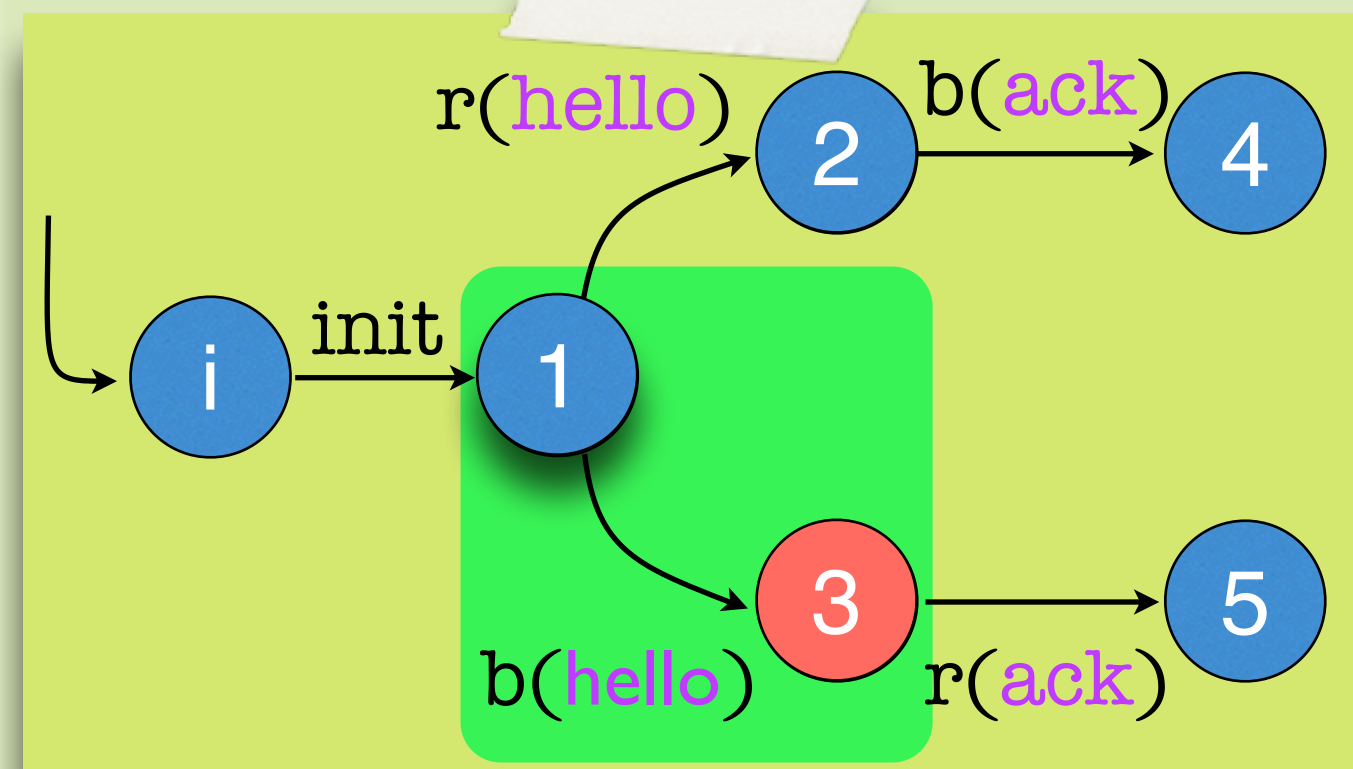

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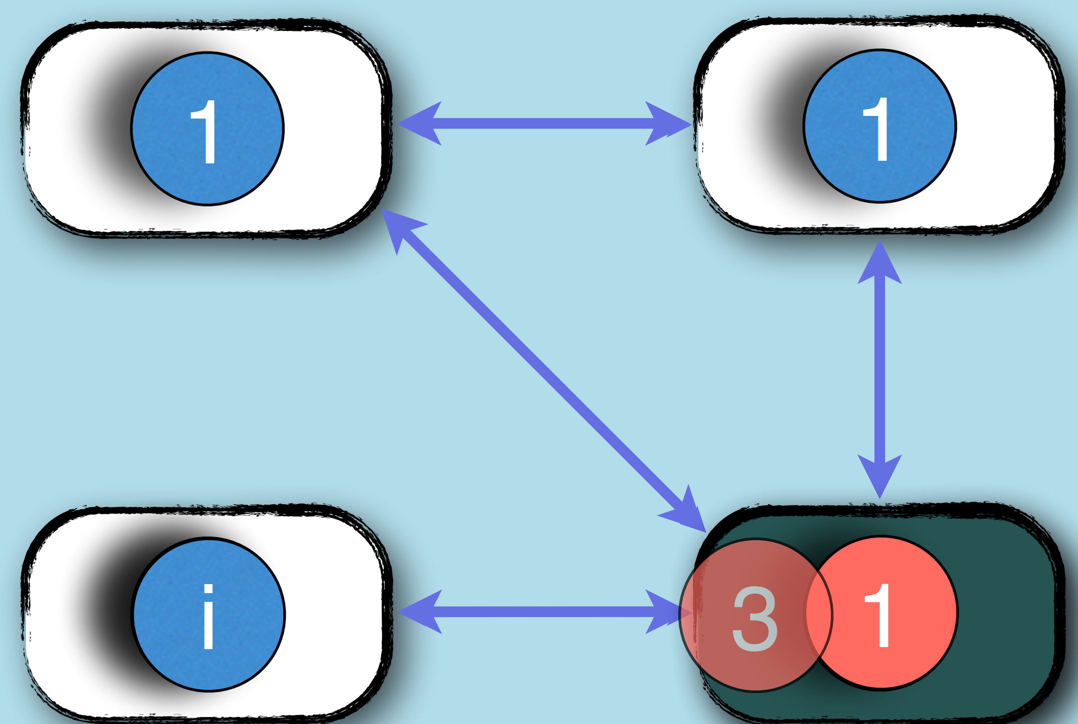
Configuration



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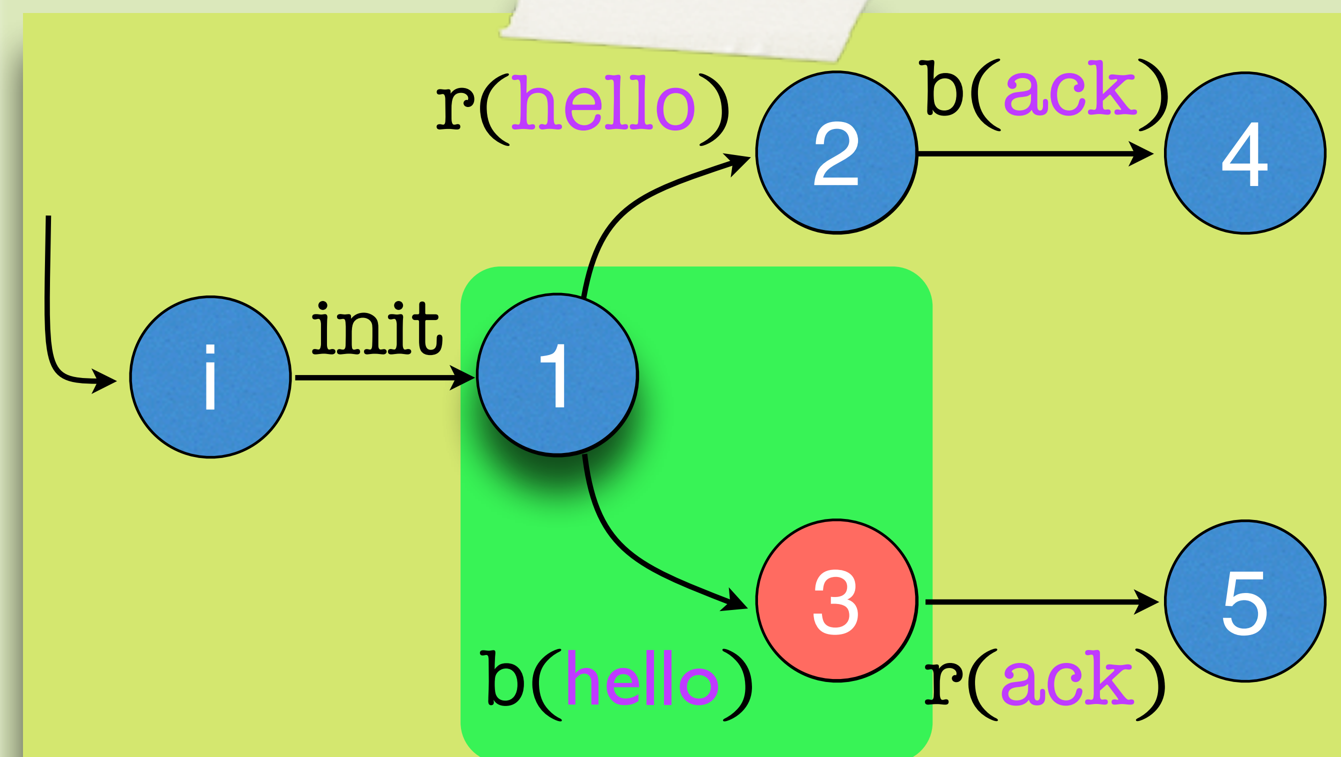
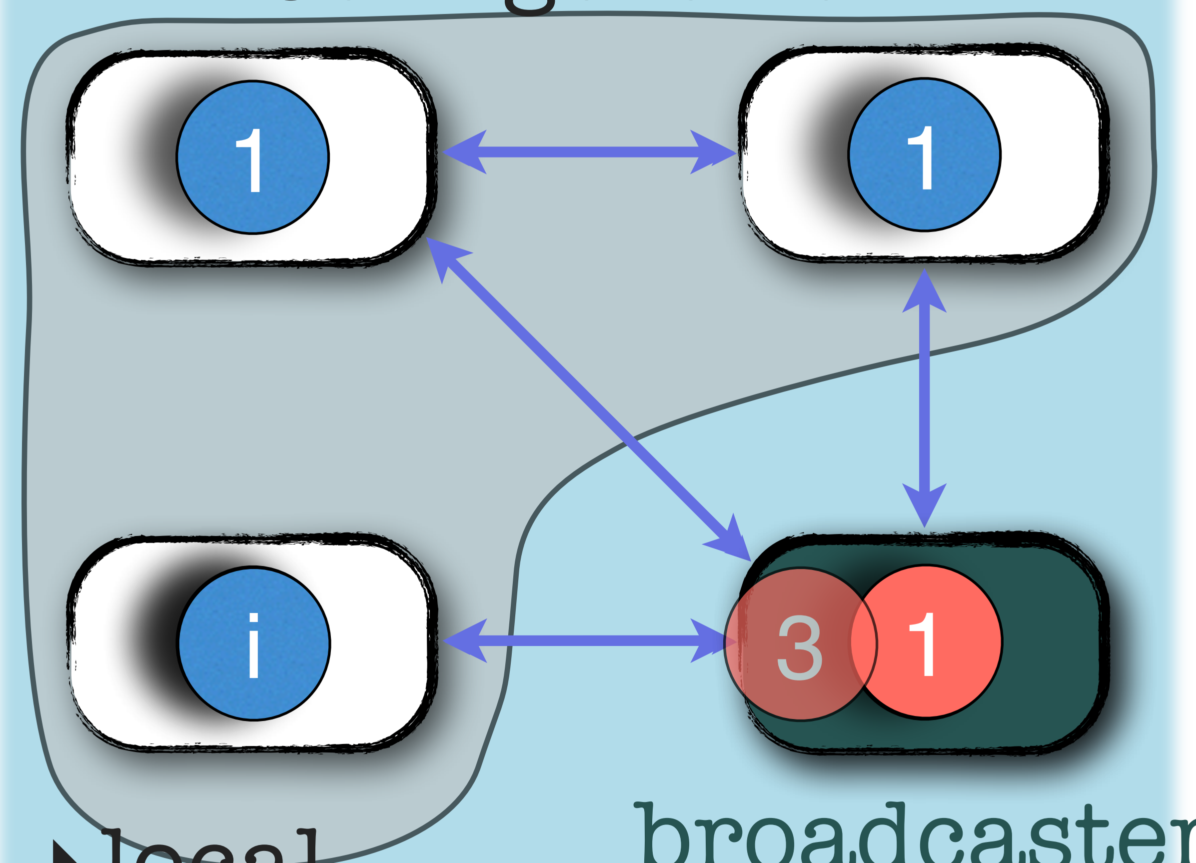


- local
- broadcast
- receive

Configuration



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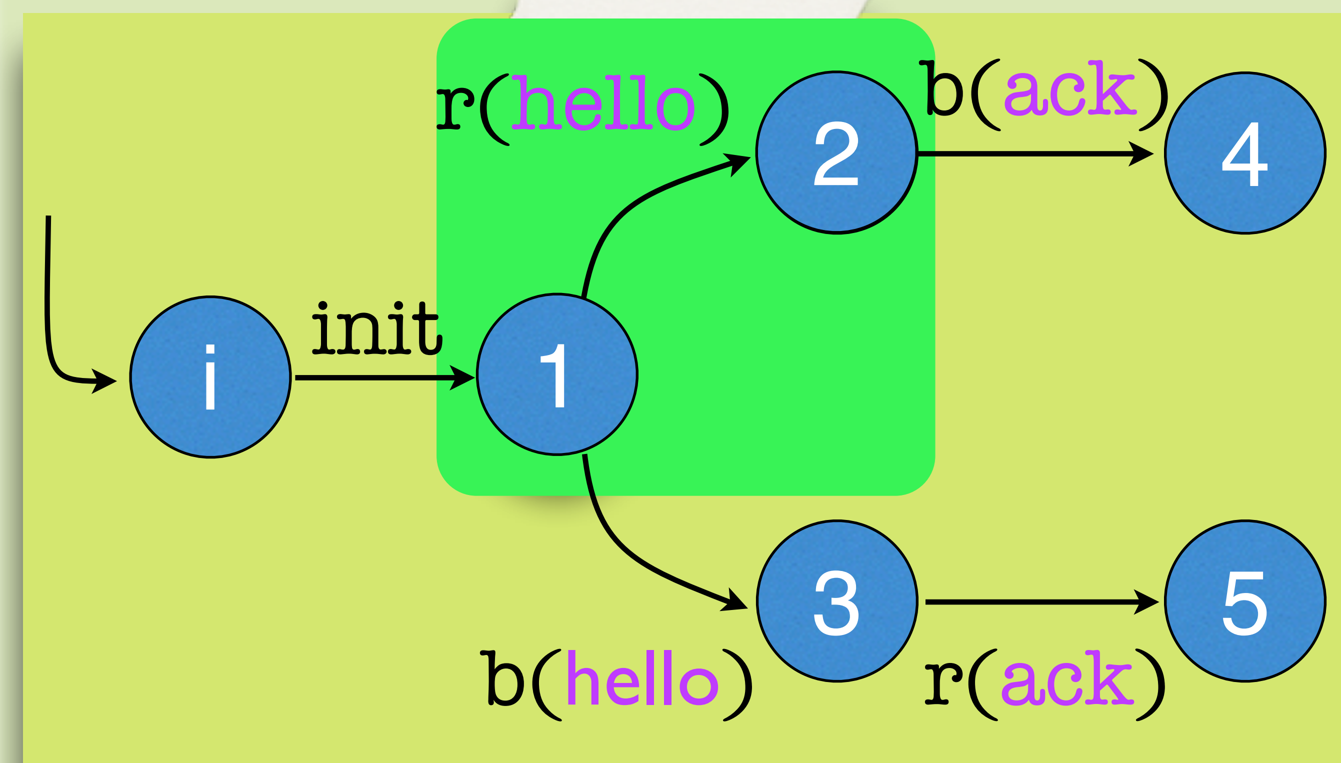

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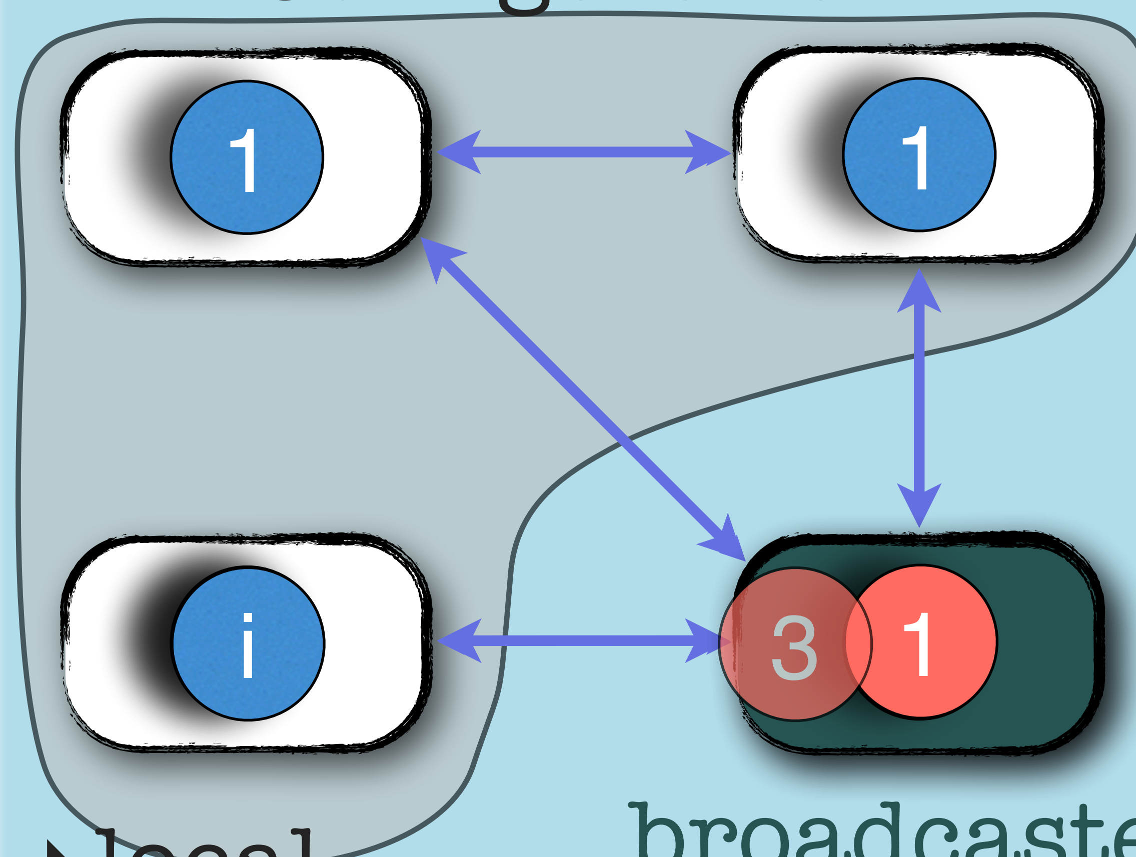
Configuration



- local
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Direct

Ad-Hoc Networks

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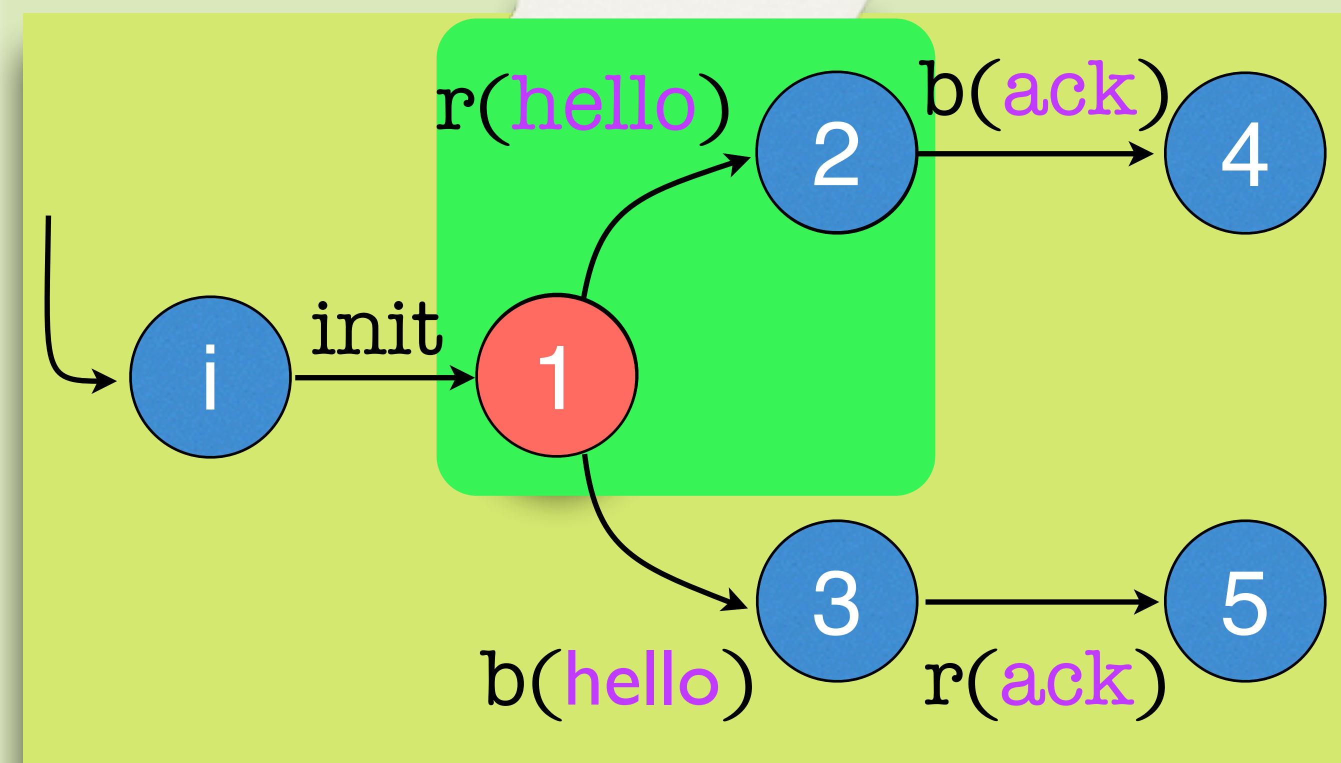
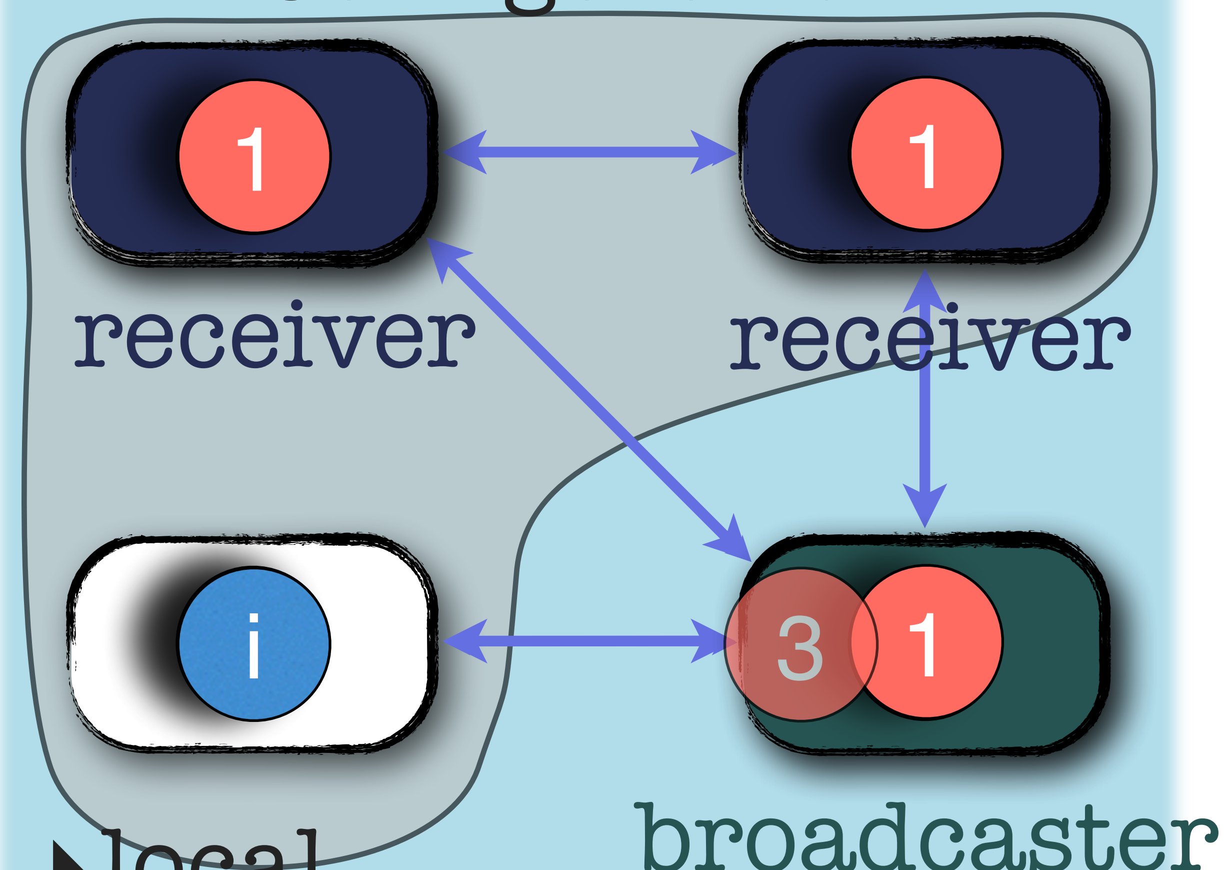
$$< \Gamma, \longrightarrow >$$

Process



- local
- broadcast
- receive

Configuration



- local
- selective broadcast

Direct

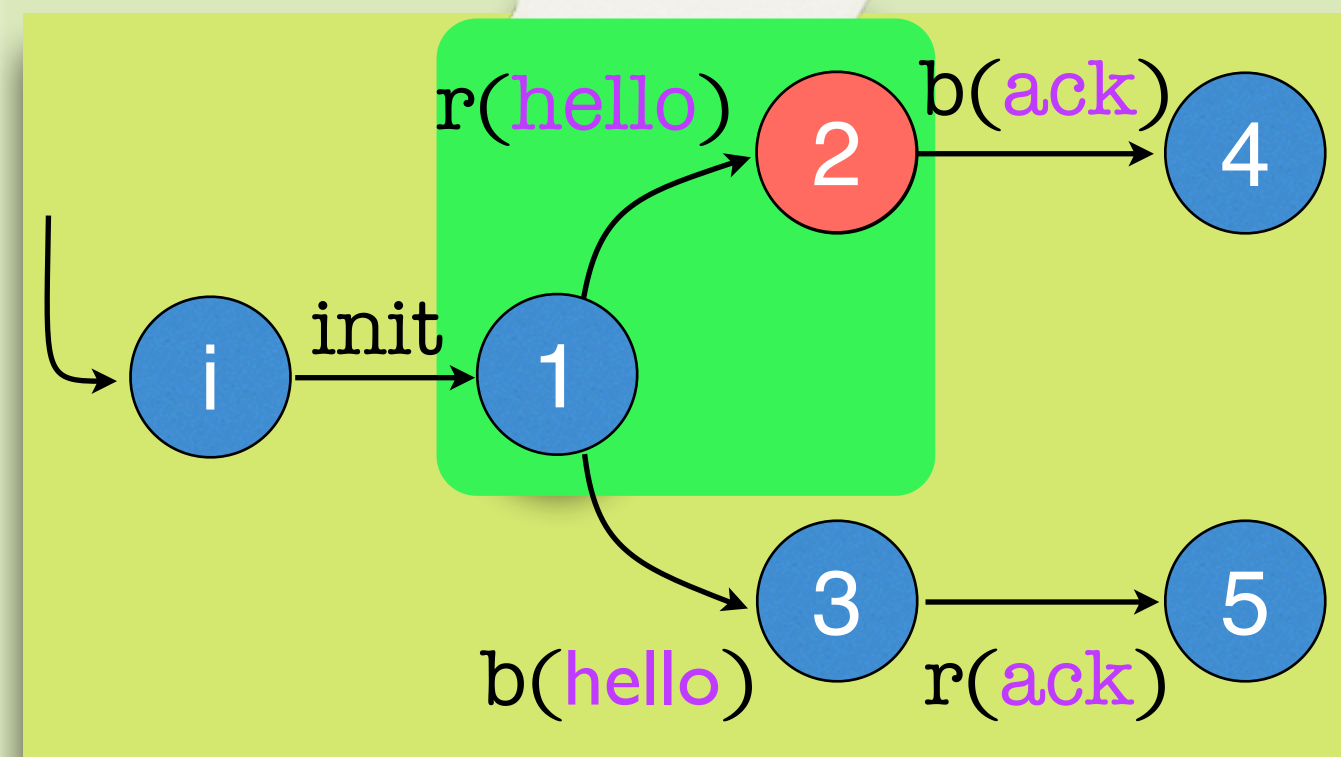
Ad-Hoc Networks

- Model
- Transition System
- Reachability

$$< \Gamma, \longrightarrow >$$

- Set of configurations
- Transition Relation
- Trace

Process



- local
- broadcast
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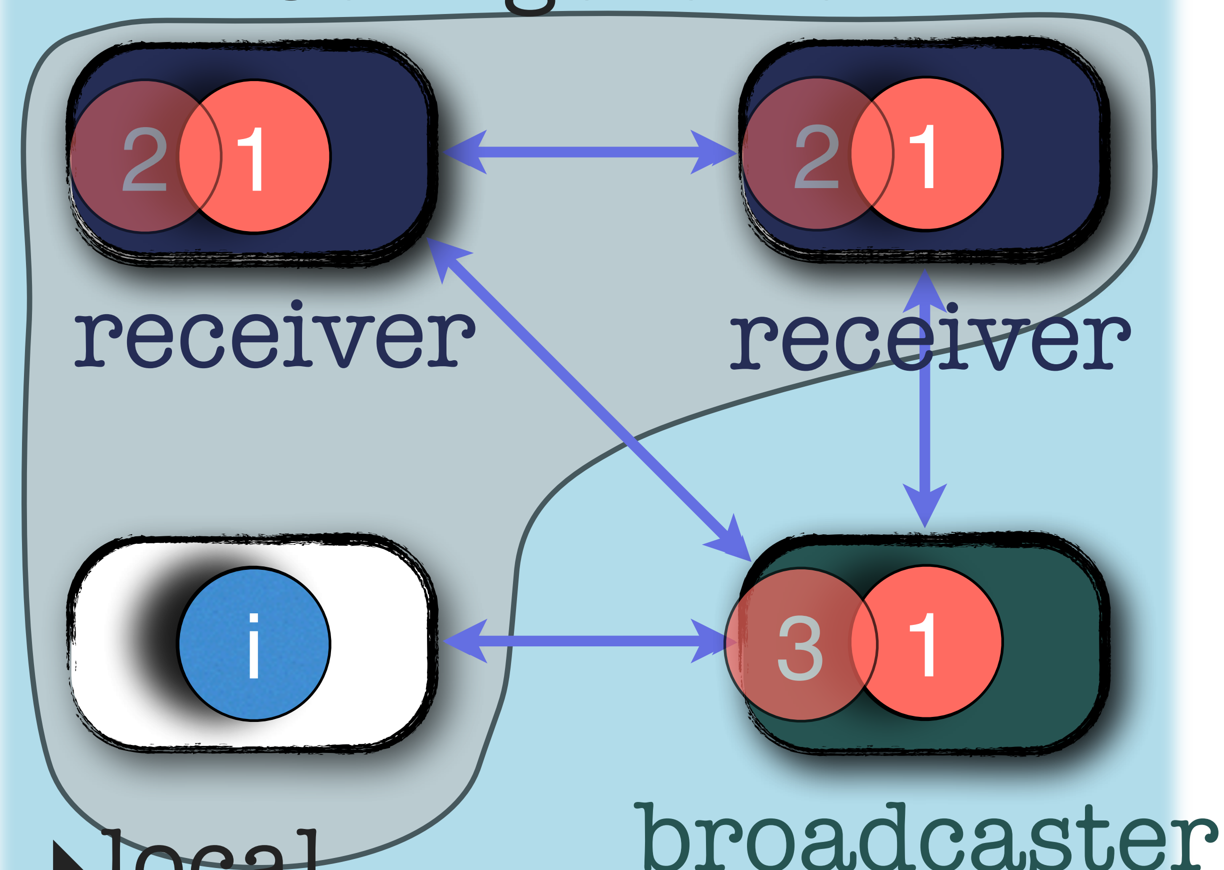
Configuration



- local
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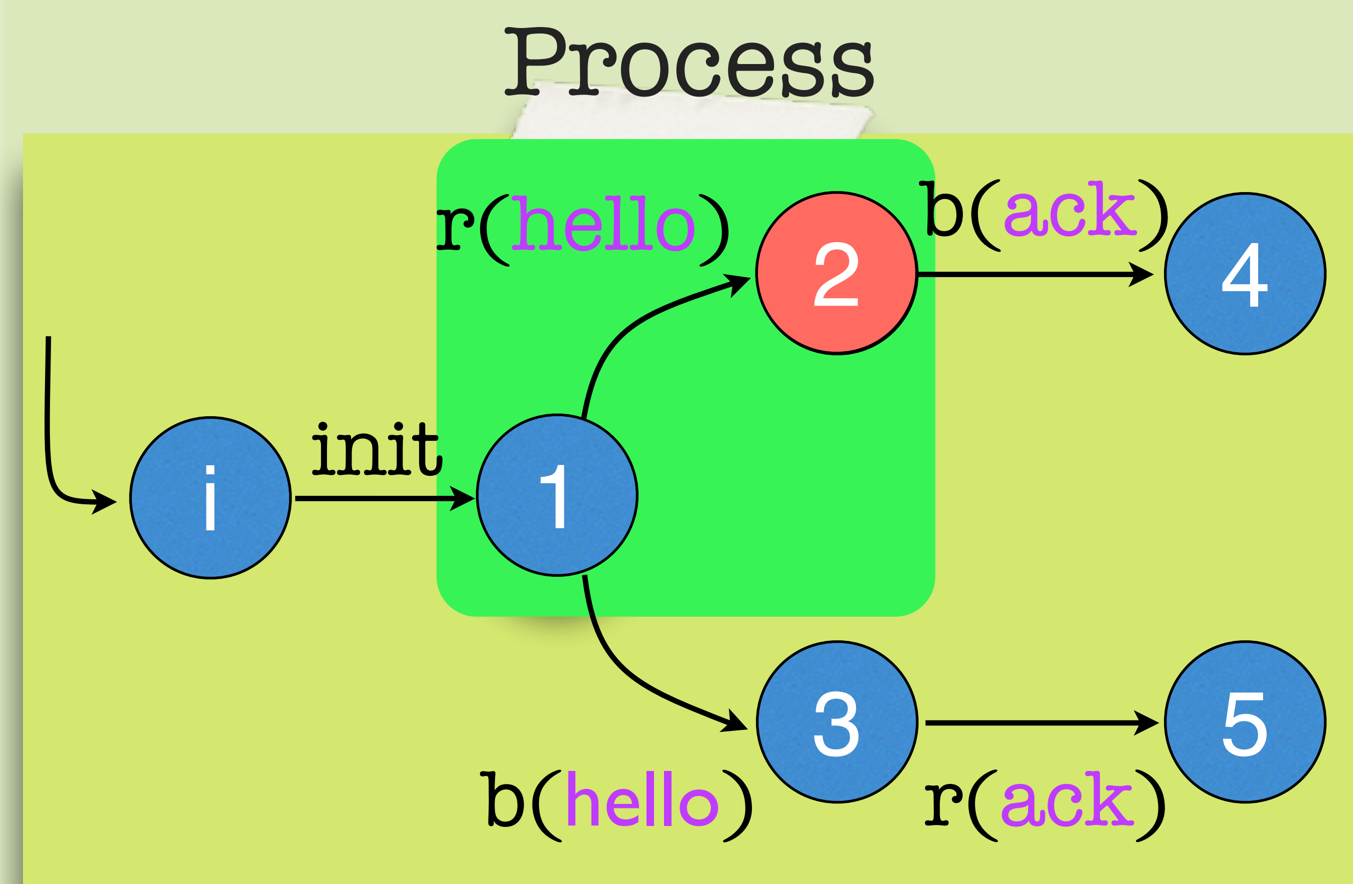
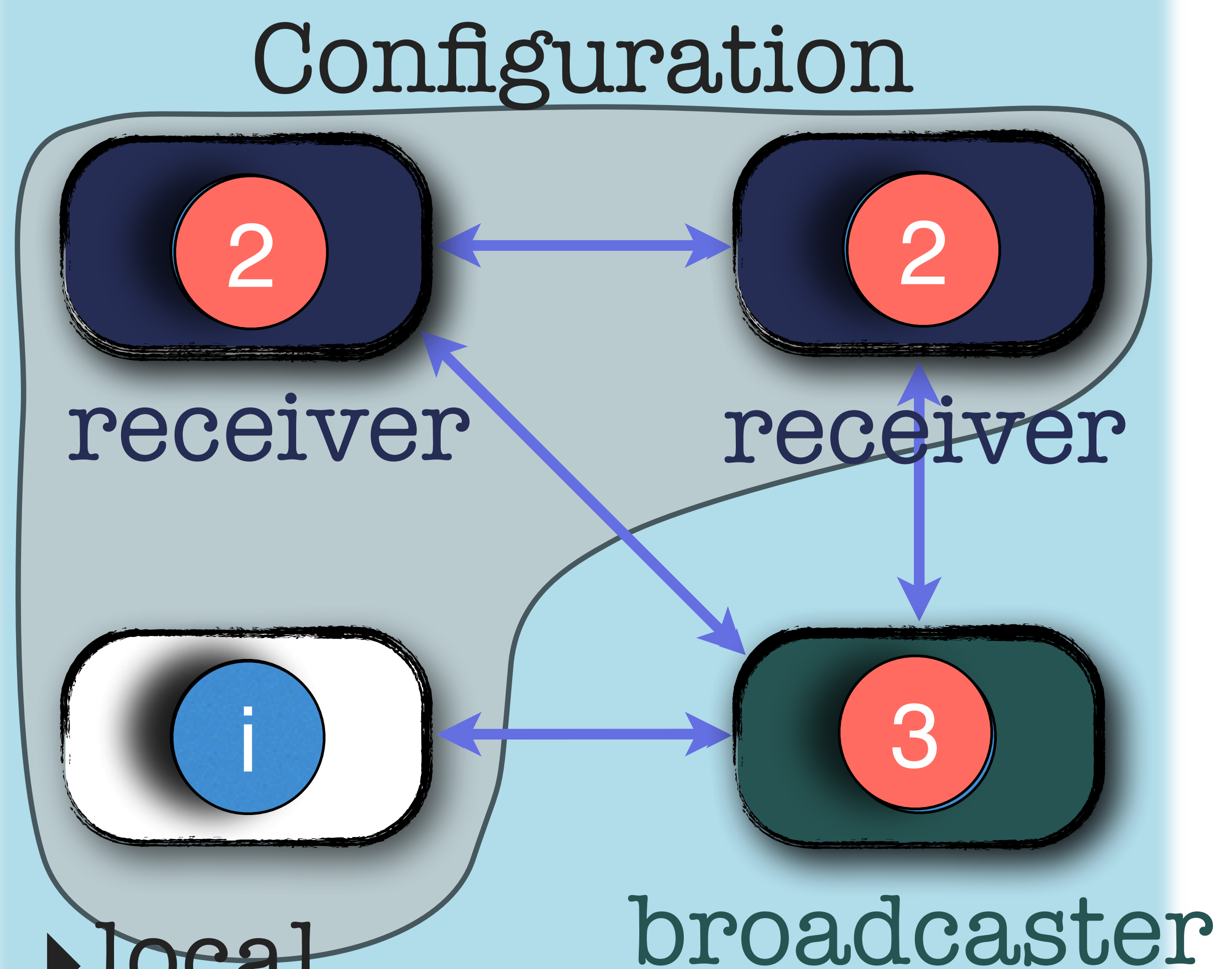
Ad-Hoc Networks

$< \Gamma, \longrightarrow >$

- Set of configurations
- Transition Relation
- Trace



- local
- broadcast
- receive



- local
- selective broadcast

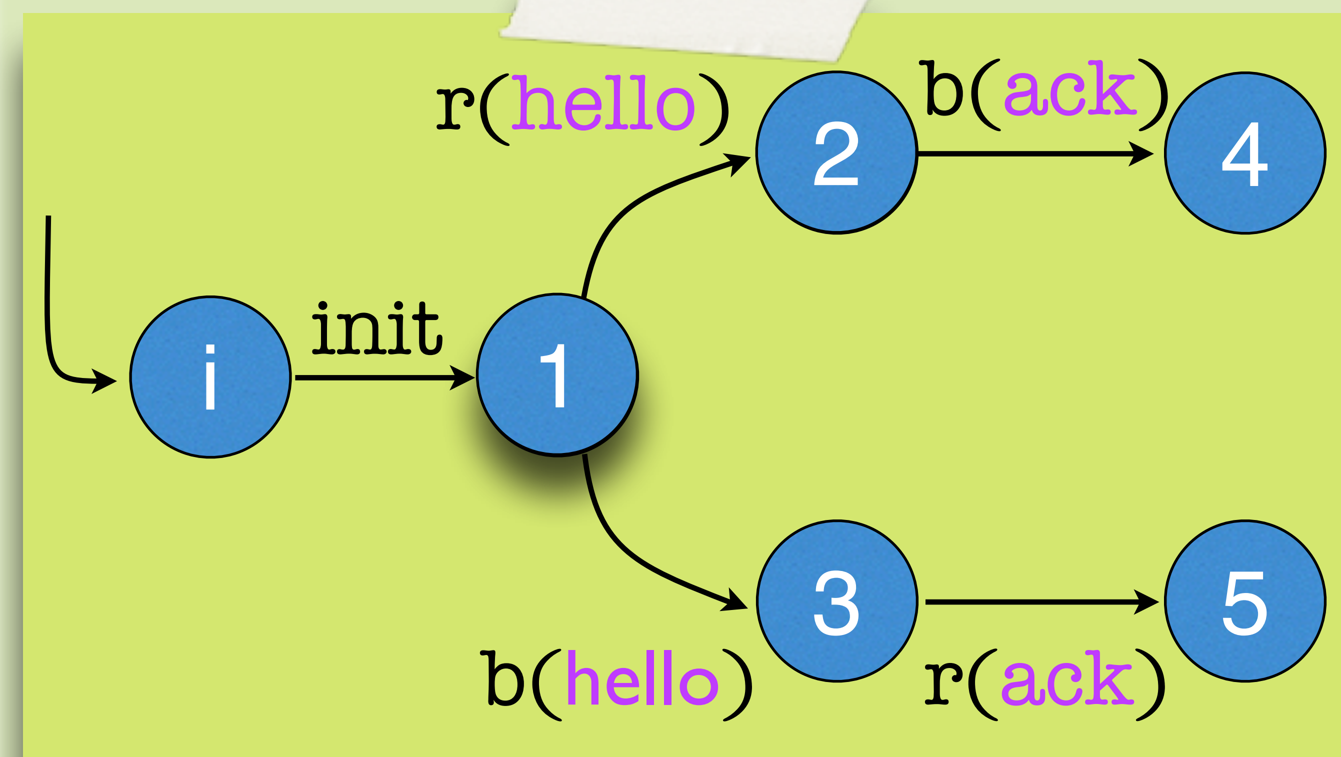
Ad-Hoc Networks

- Model
- Transition System
- Reachability

$$< \Gamma, \longrightarrow >$$

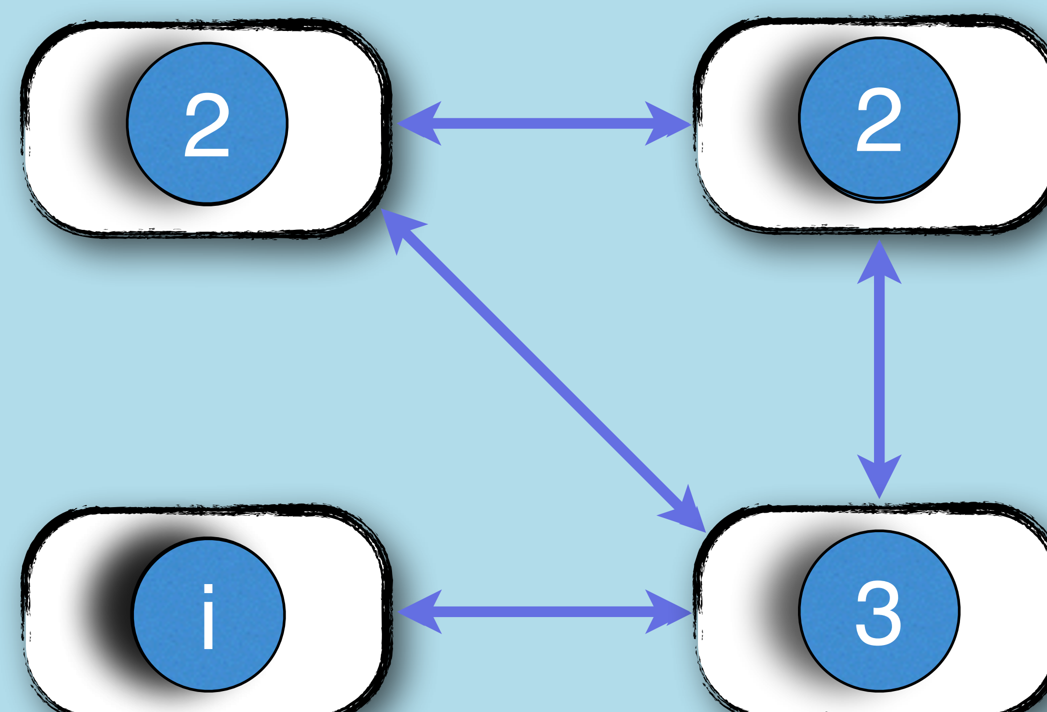
- Set of configurations
- **Transition Relation**
- Trace

Process



- local
- broadcast
- receive

Configuration



- local
- selective broadcast

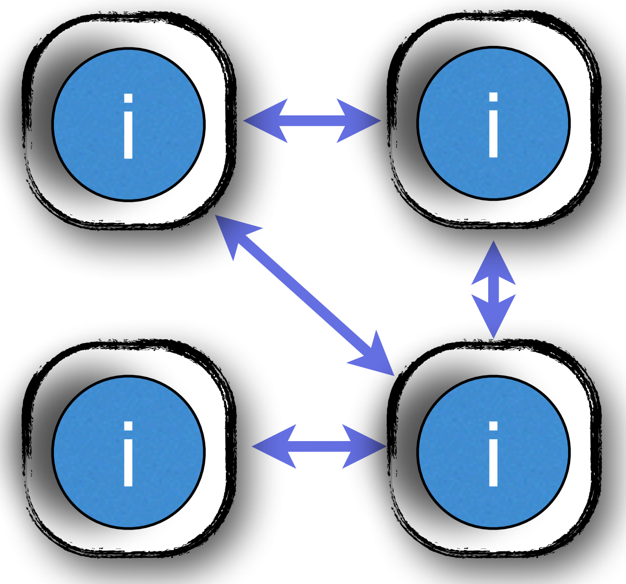
Direct

Ad-Hoc Networks

$< \Gamma, \longrightarrow >$

- Set of configurations
- Transition Relation
- Trace

Conf

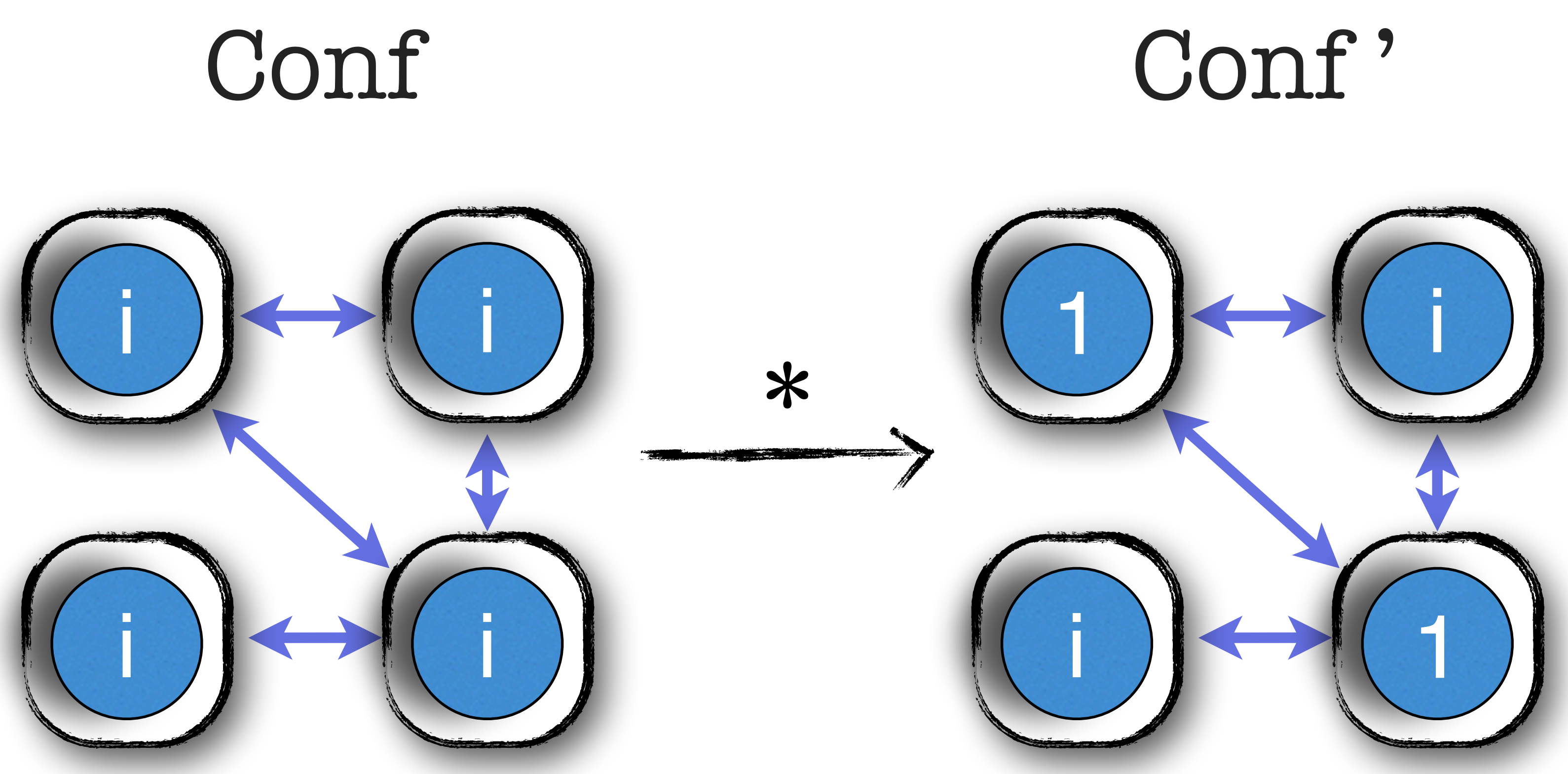


Ad-Hoc Networks

- Model
- Transition System
- Reachability

$< \Gamma, \longrightarrow >$

- Set of configurations
- Transition Relation
- Trace



Ad-Hoc Networks

- Model
- Transition System
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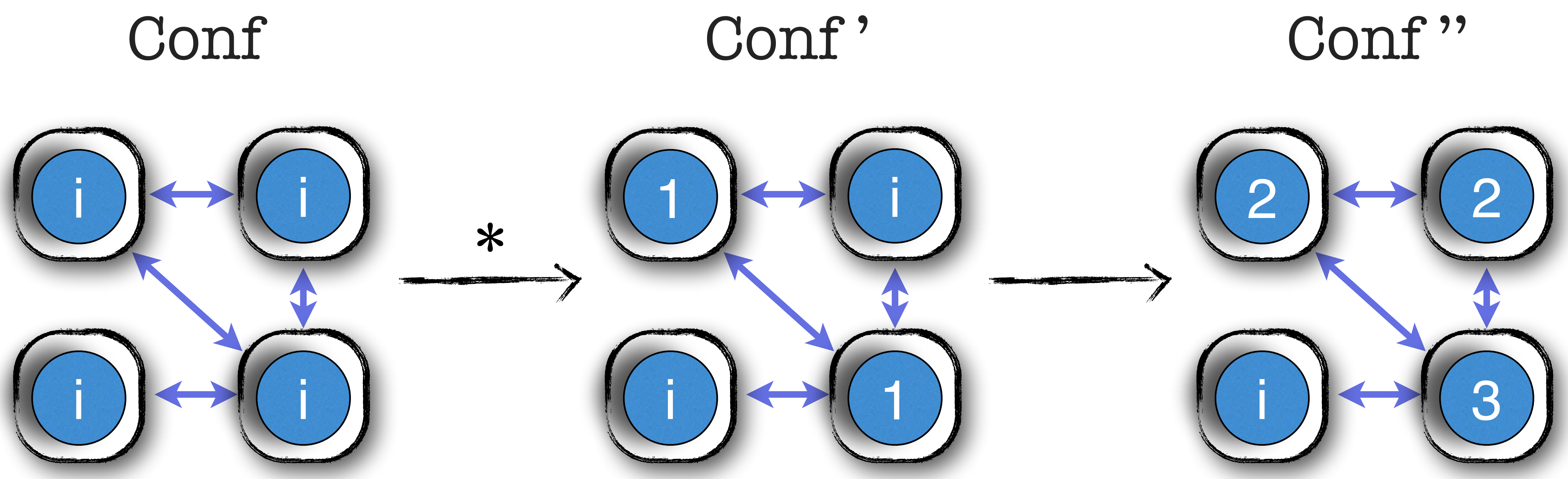


Direct

Control State Reachability (COVER)

Control State Reachability (COVER)

Control State Reachability (COVER)

Given

Ad-Hoc Networks

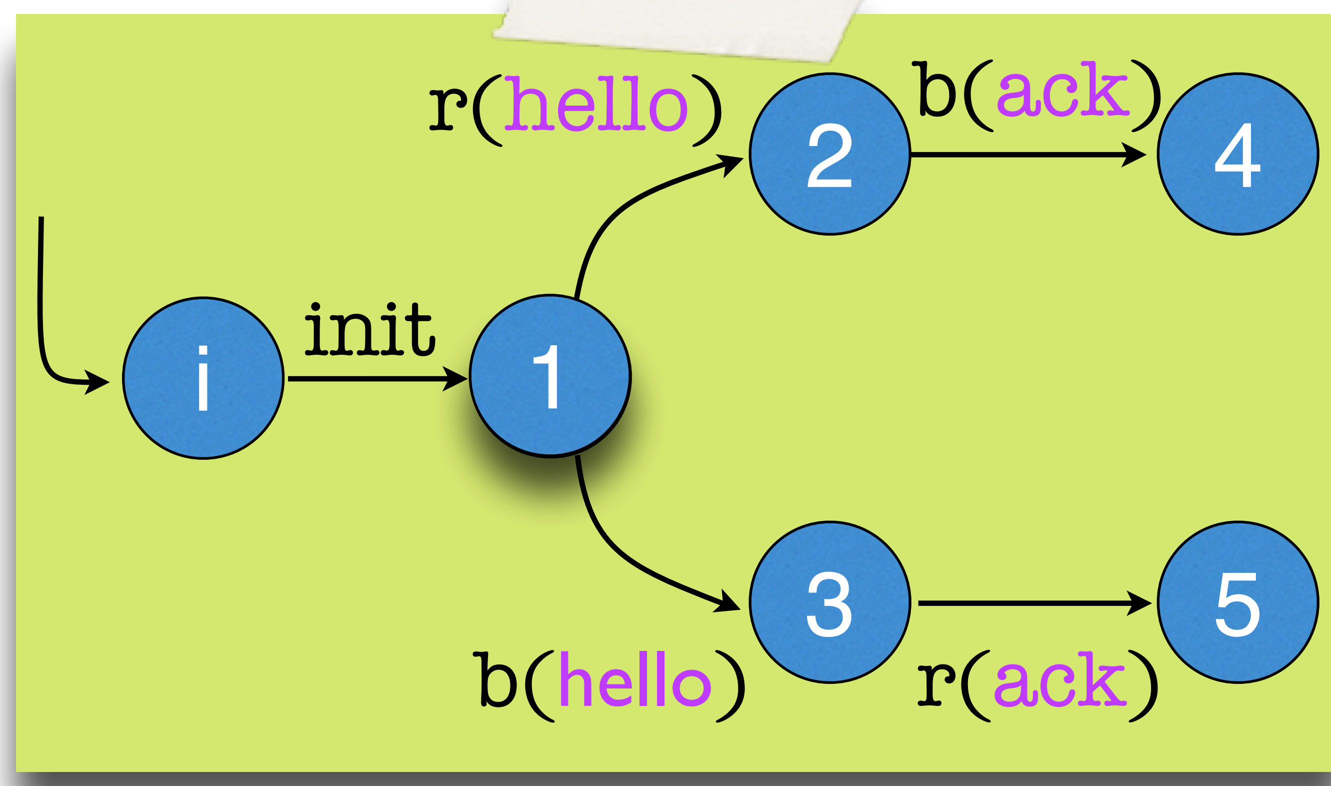
- Model
- Transition System
- Reachability

Control State Reachability (COVER)

Given

- Process P

Process



Direct

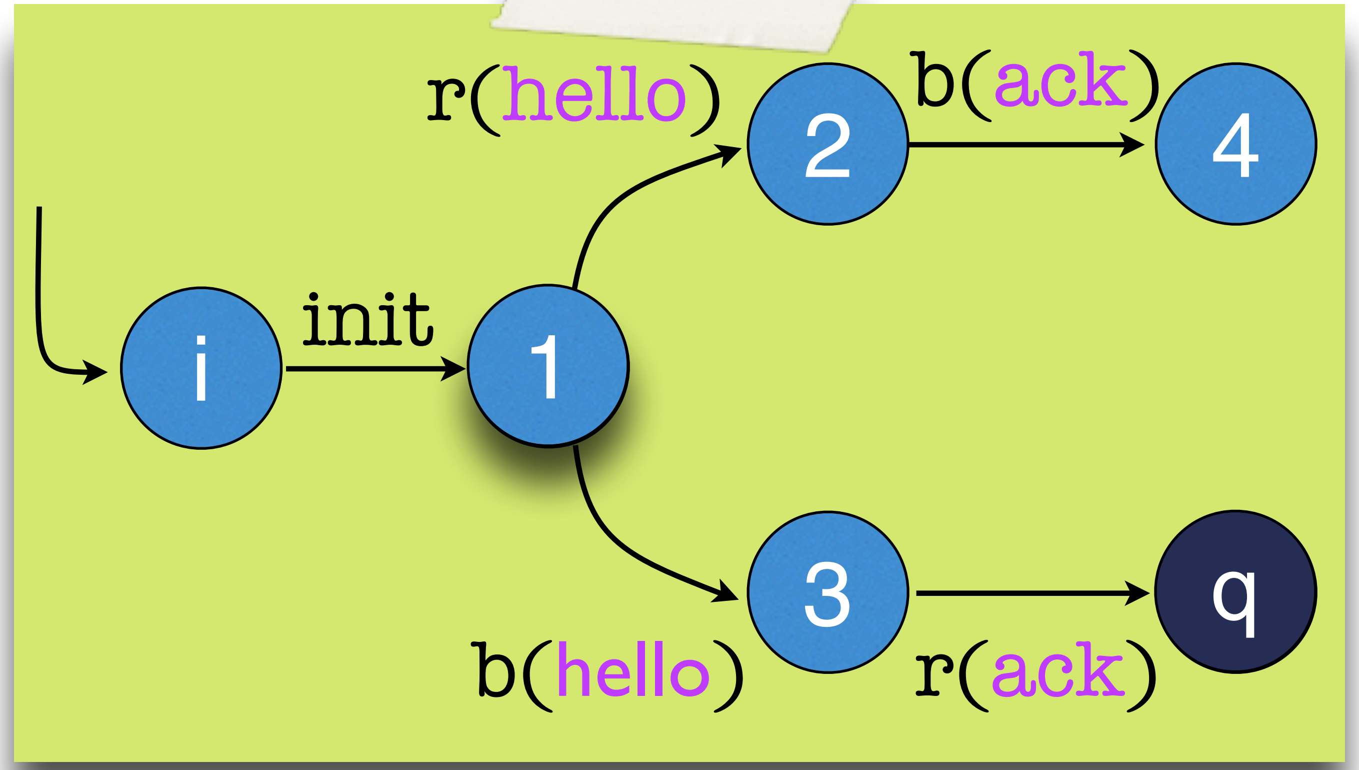
Ad-Hoc Networks

Control State Reachability (COVER)

Given

- Process P
- Control State q

Process



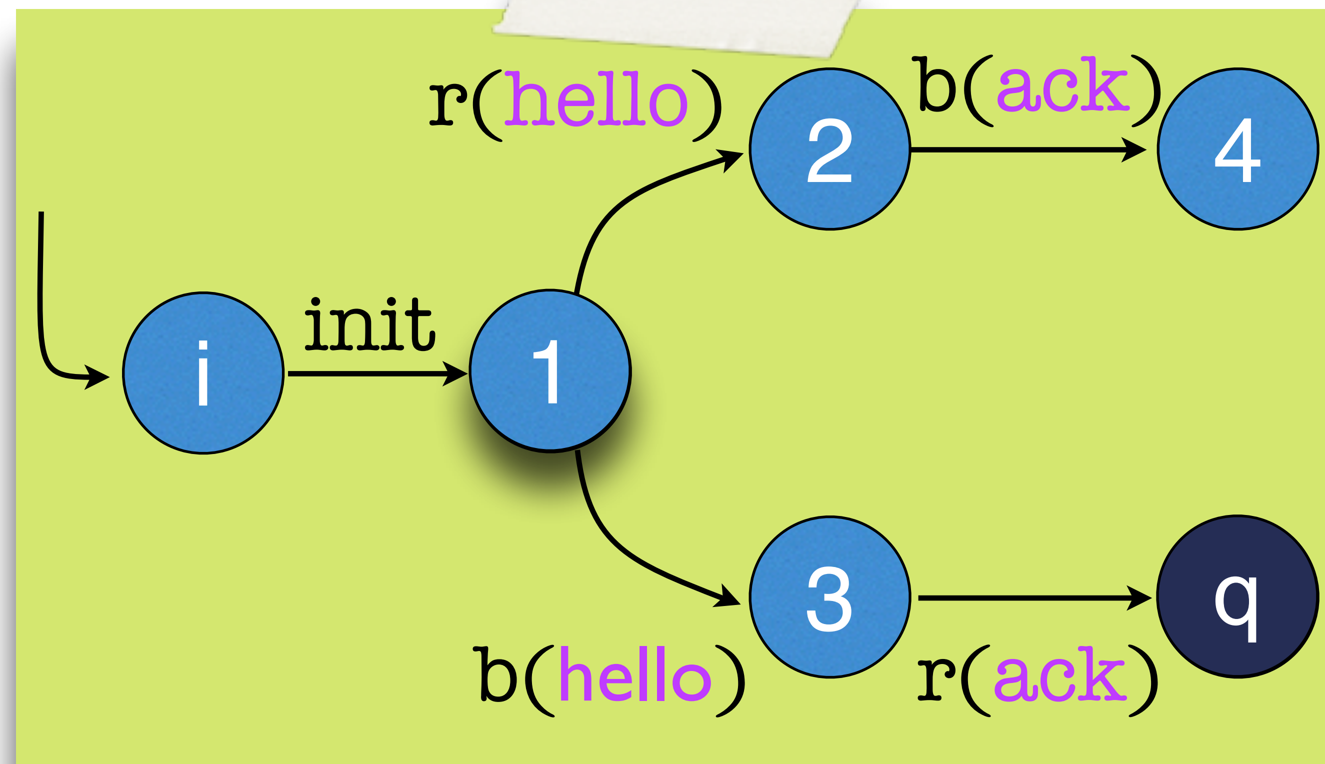
Ad-Hoc Networks

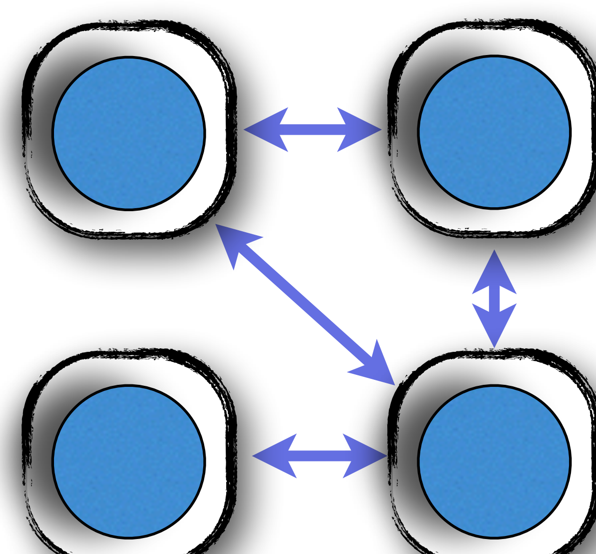
- Model
- Transition System
- Reachability

Control State Reachability (COVER)

Given
- Process P
- Control State q

Process



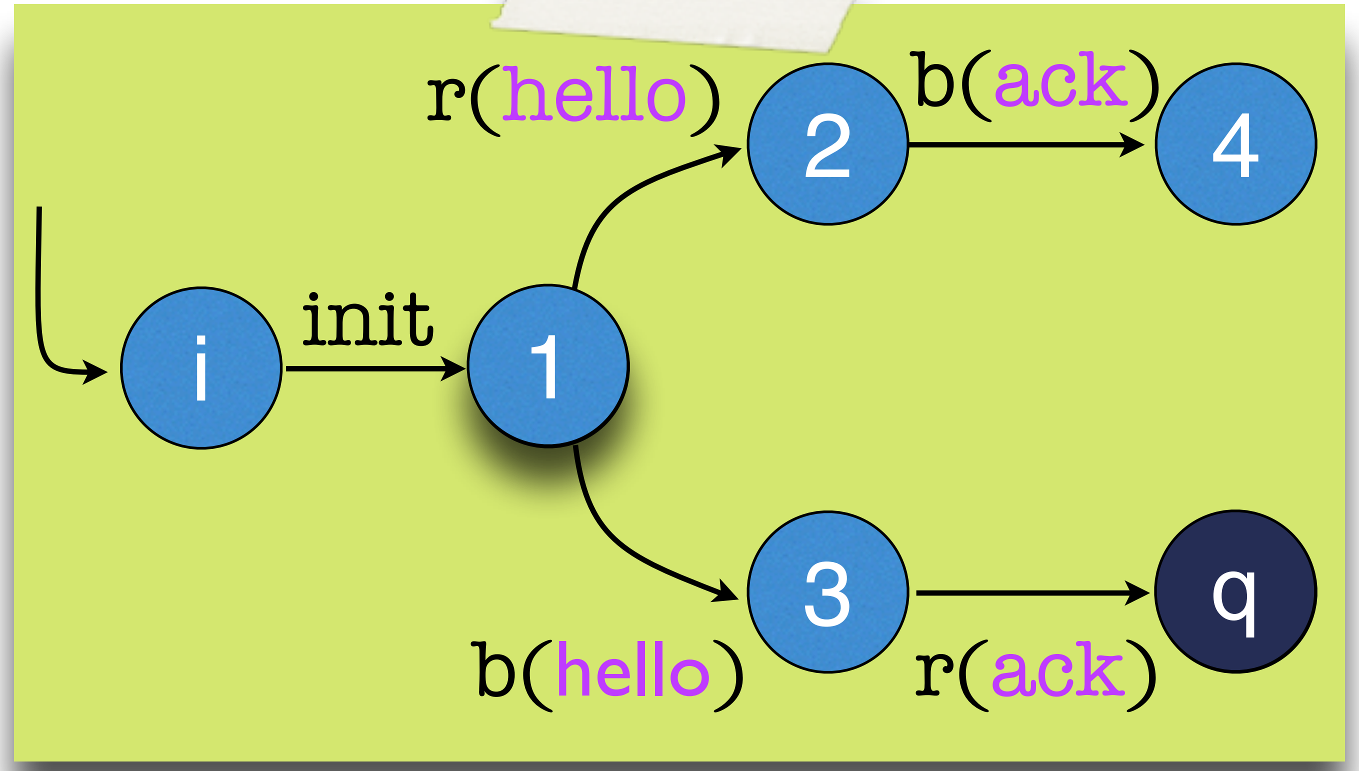


Direct

Ad-Hoc Networks

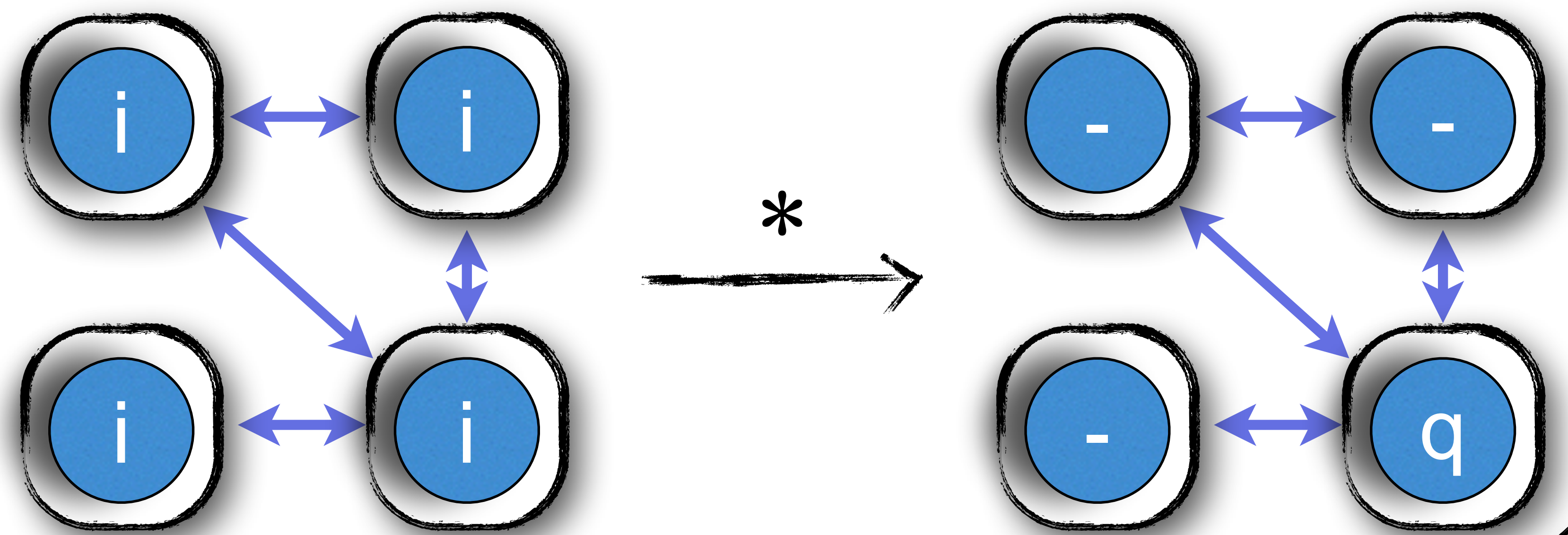
- Model
- Transition System
- Reachability

Process



Control State Reachability (COVER)

Given
- Process P
- Control State q



Direct

Control State Reachability (COVER)

Undecidable

Ad-Hoc Networks

Directed Acyclic

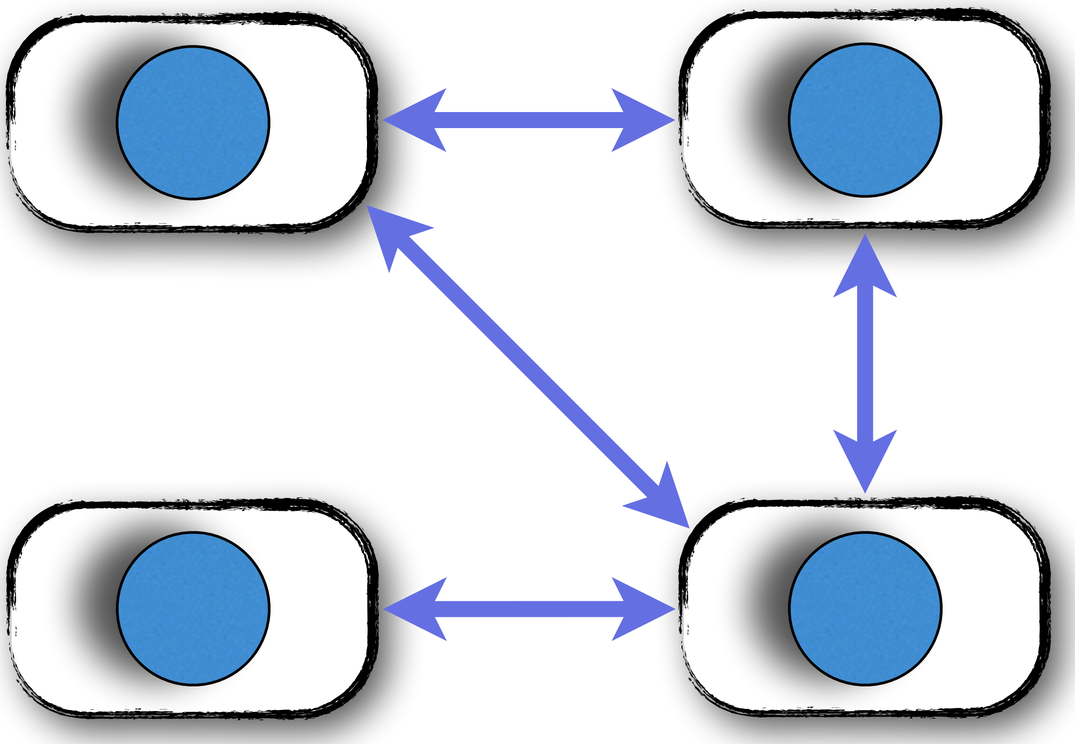
Ad-Hoc Networks

Directed Acyclic

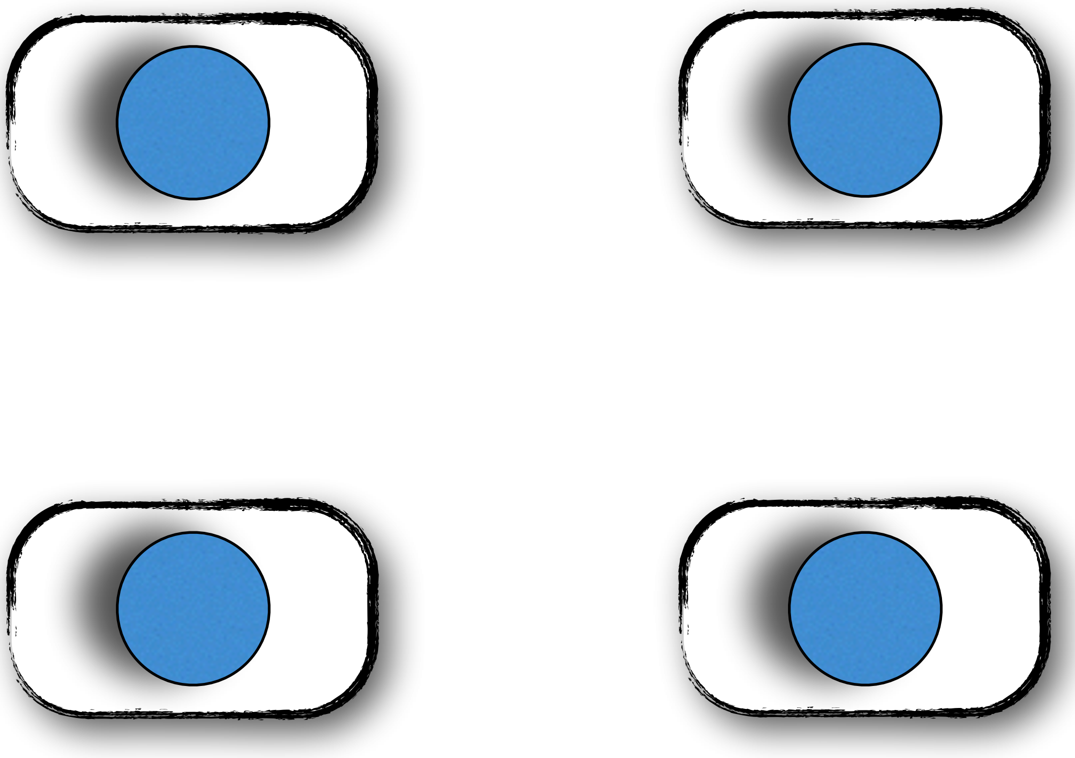
- Motivation
- Reachability
- Bounded Depth Reachability

Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability



Directed Acyclic



Directed Acyclic

- Motivation
- Reachability
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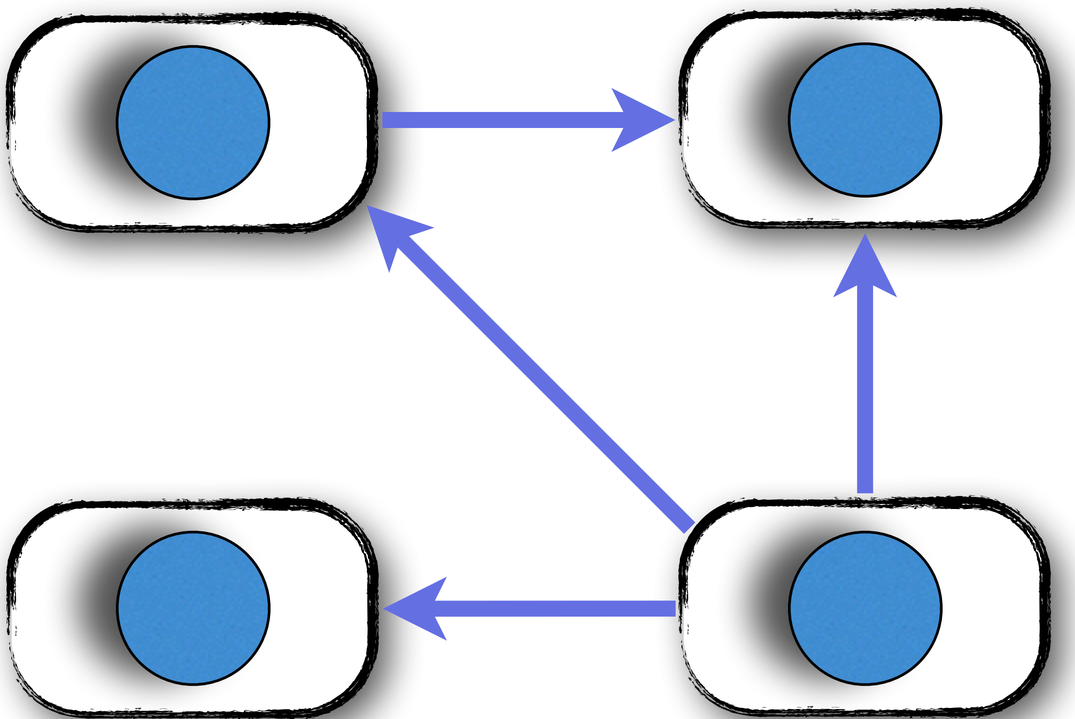


Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

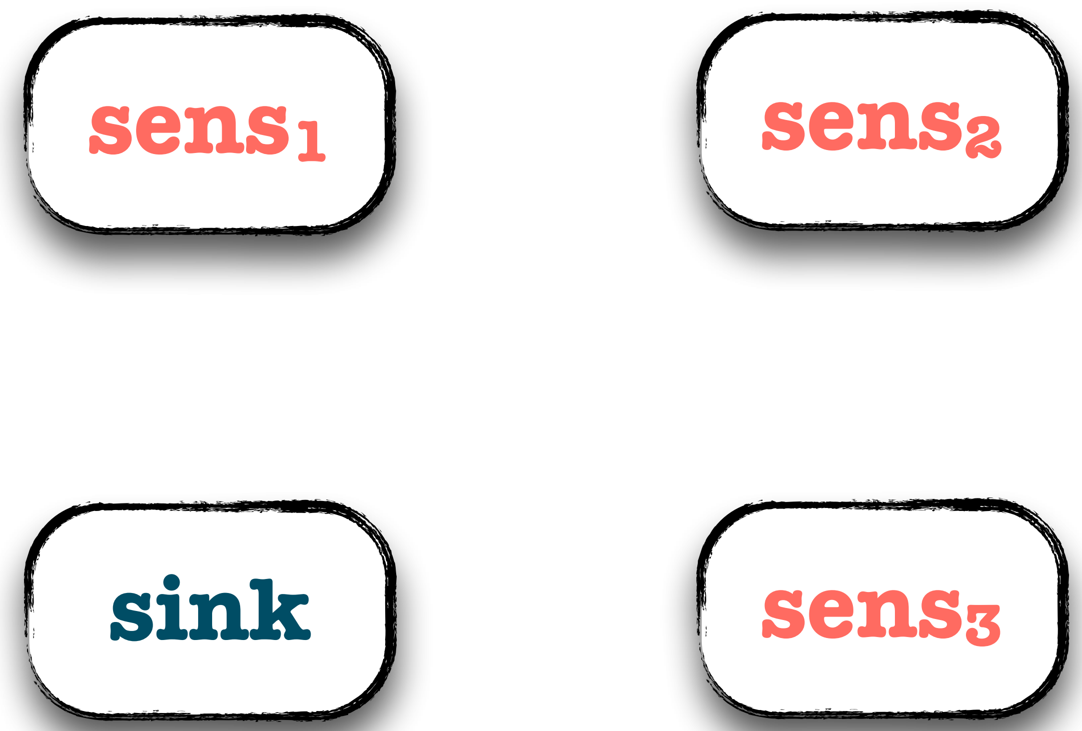
Directed Acyclic

Wireless Sensor Networks

Directed Acyclic

Wireless Sensor Networks

Phases:

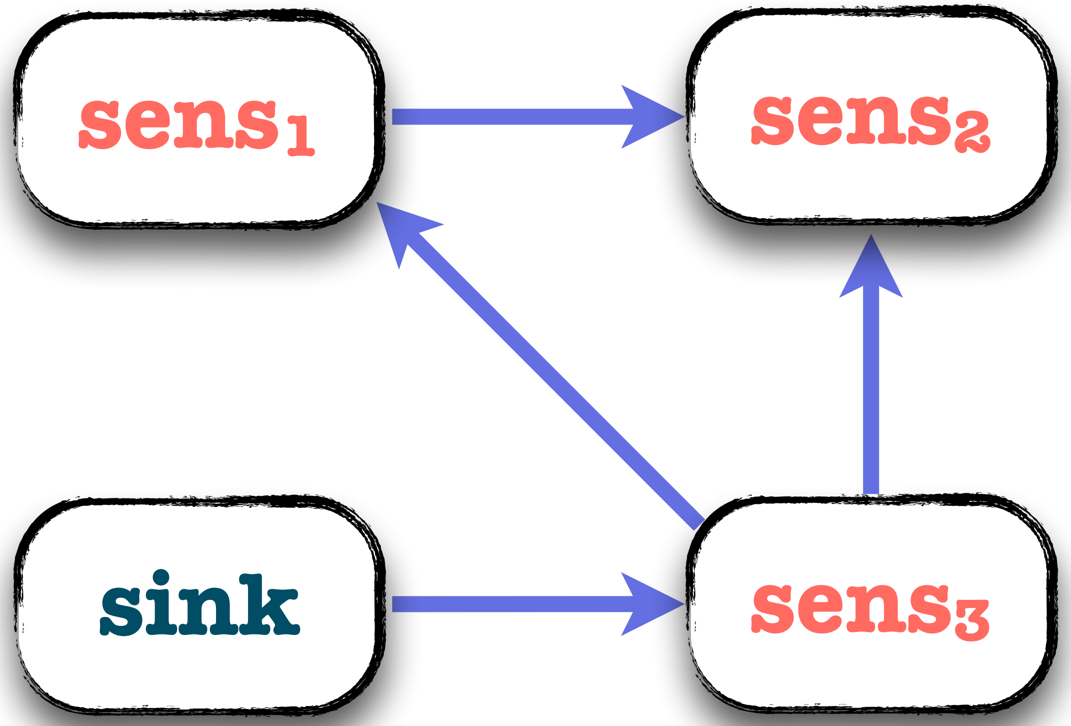


Directed Acyclic

Wireless Sensor Networks

Phases:

- Sink → Sensors:
  - Data request
  - Software updates
- Sensors → Sink:
  Data collection.



Directed Acyclic

- Motivation
- Reachability
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Wireless Sensor Networks

Phases:

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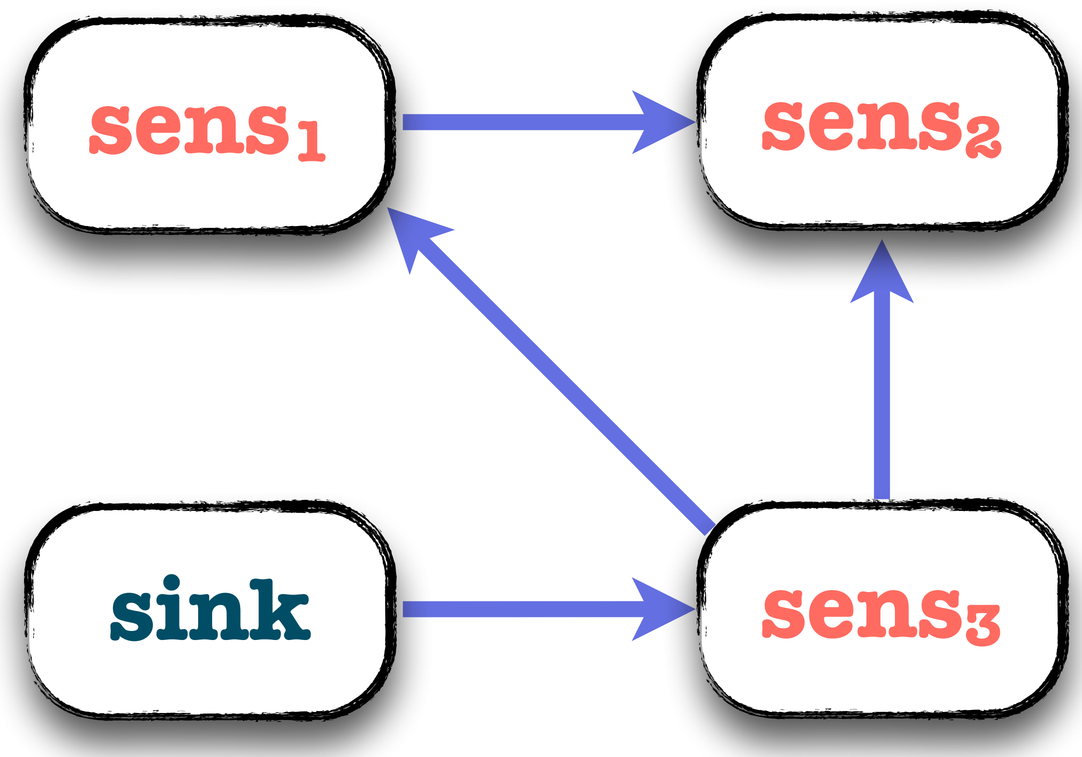

Directed Acyclic

Wireless Sensor Networks

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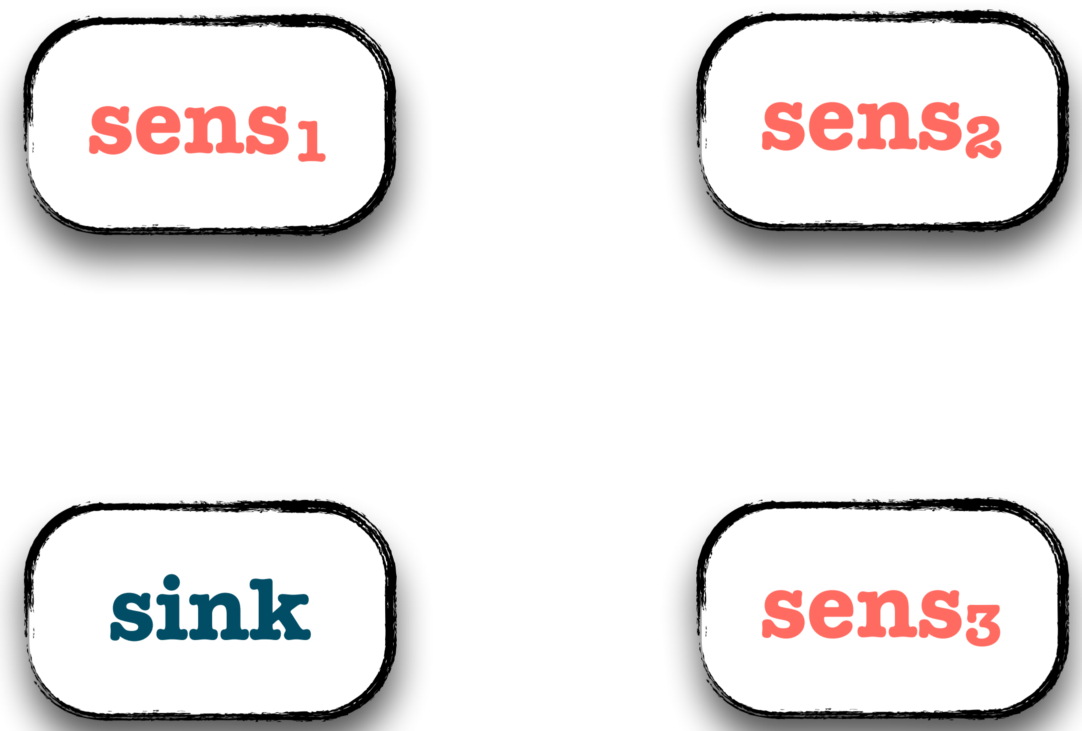

Directed Acyclic

Wireless Sensor Networks

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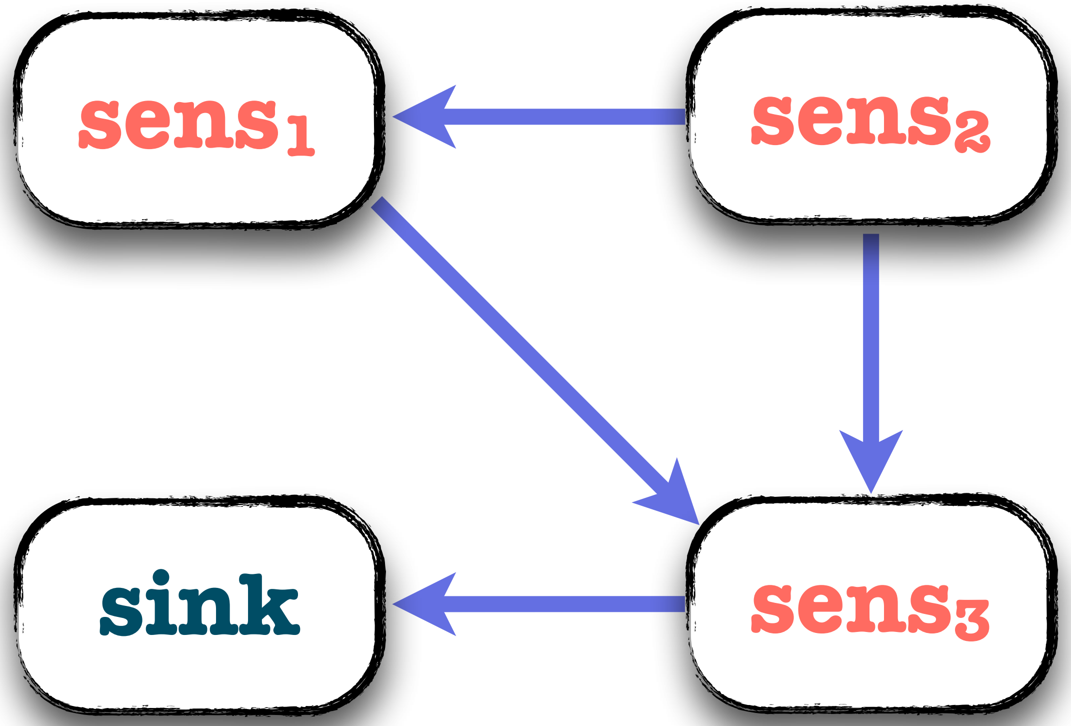

Directed Acyclic

Wireless Sensor Networks

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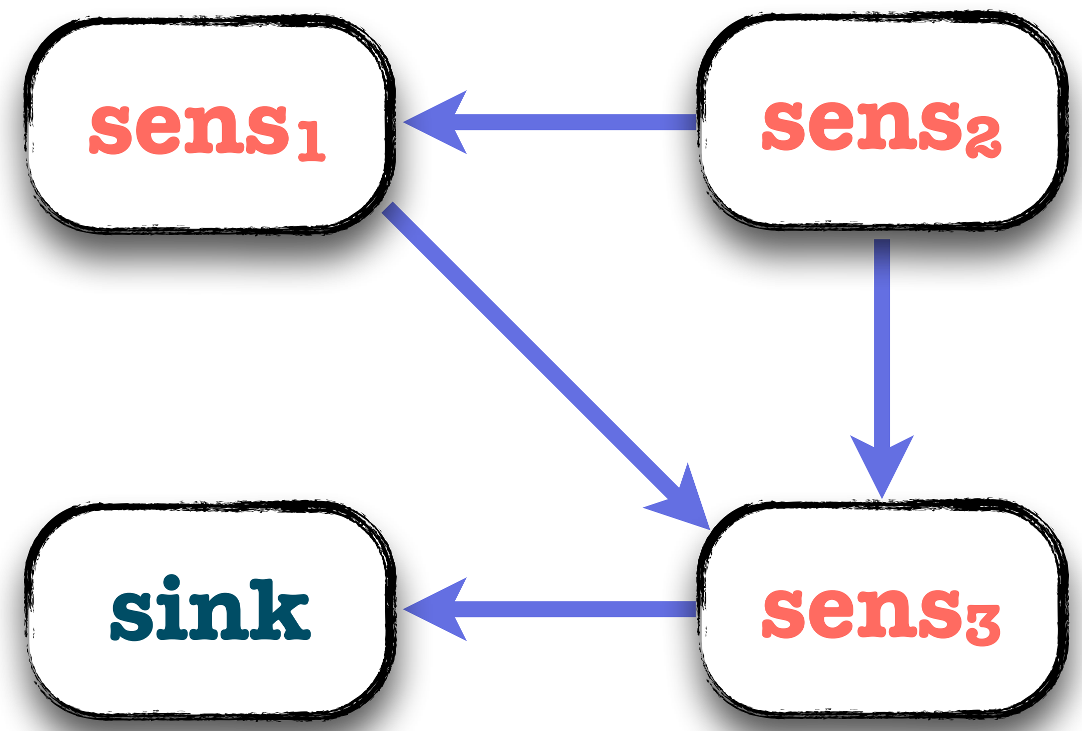


Root Discovery Protocol

Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

Directed Acyclic

Directed Acyclic

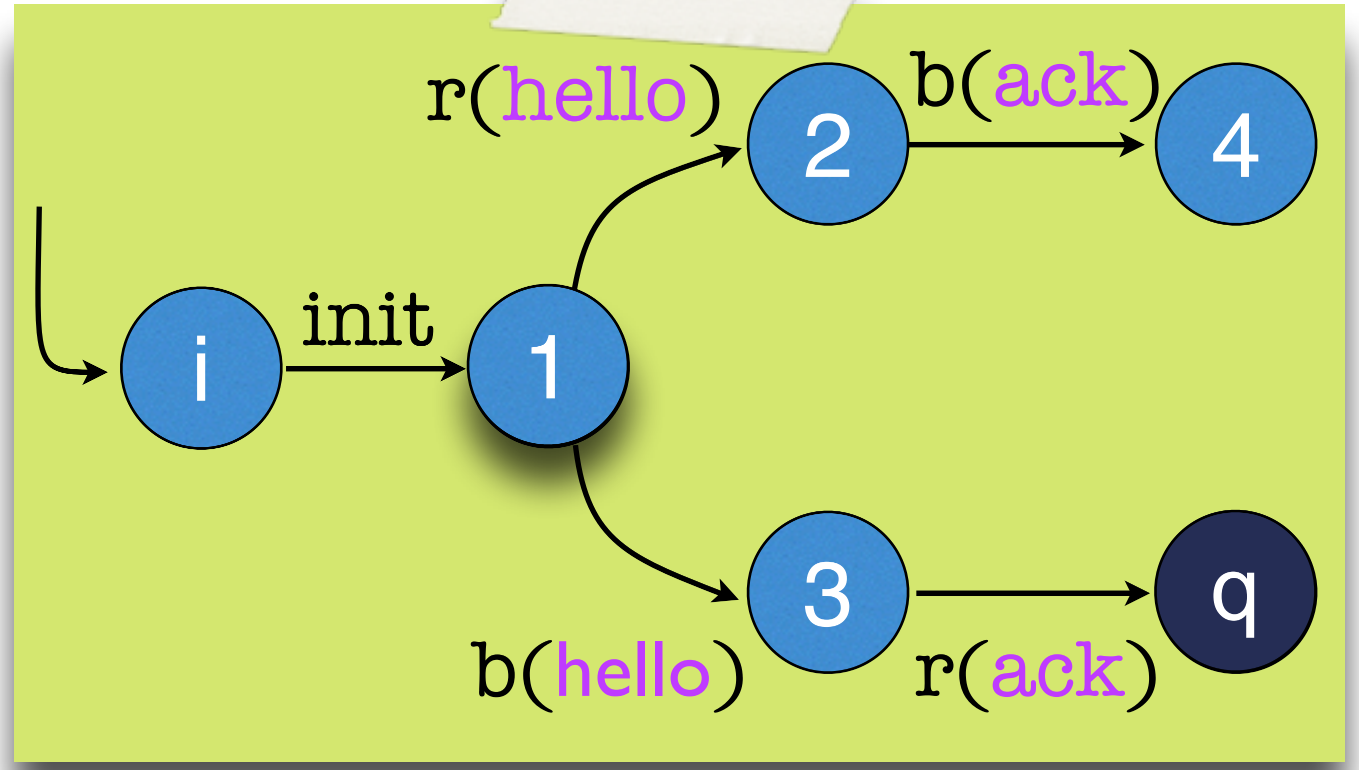
- Motivation
- **Reachability**
- Bounded Depth Reachability

Control State Reachability (COVER)

Given

- Process P
- Control State q

Process



Directed Acyclic

- Motivation
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Control State Reachability (COVER)

Given
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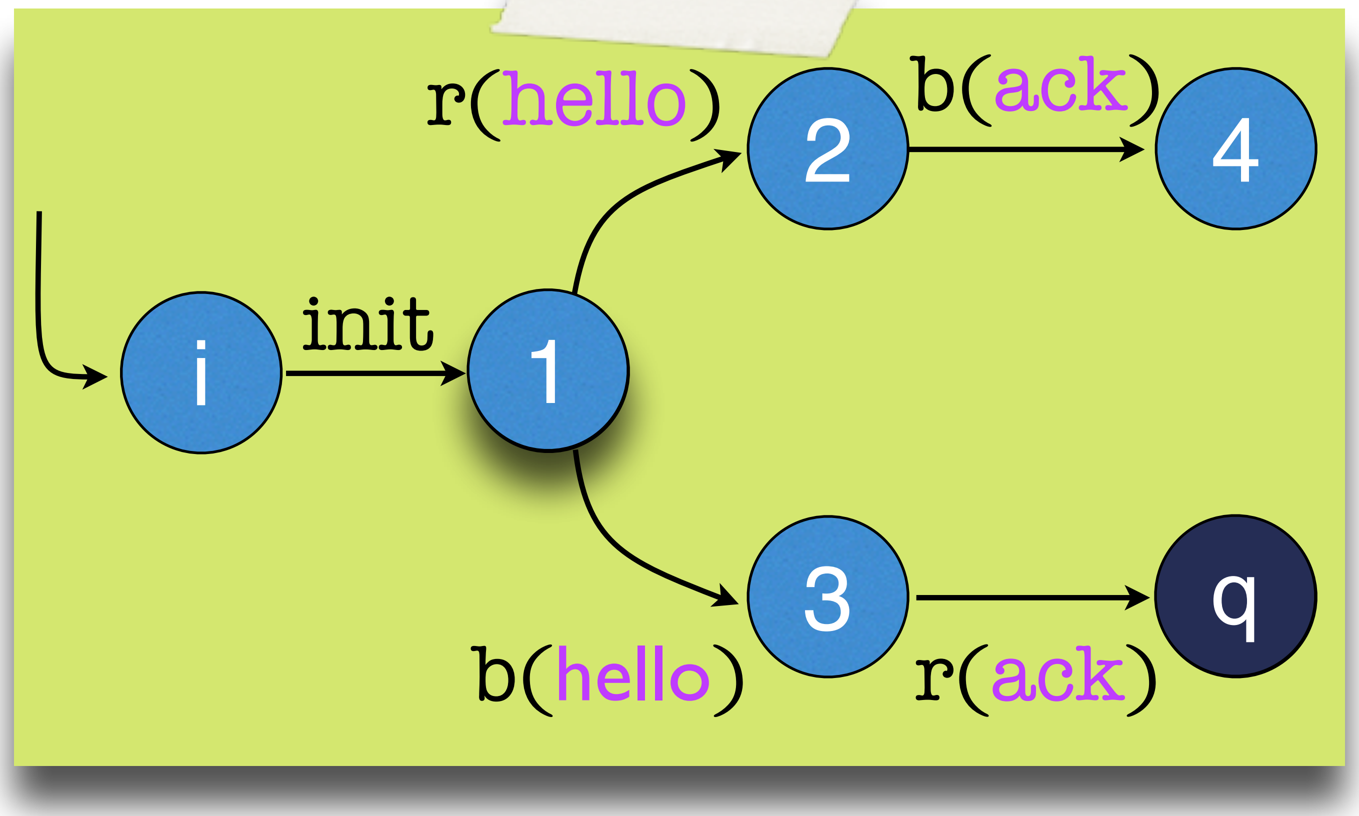
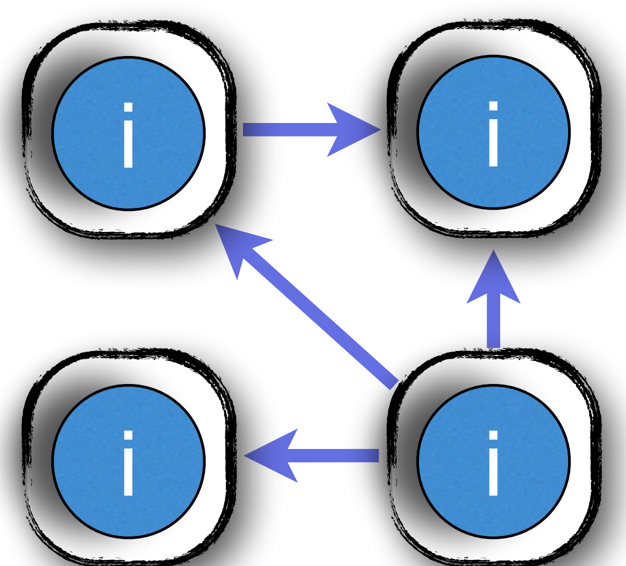




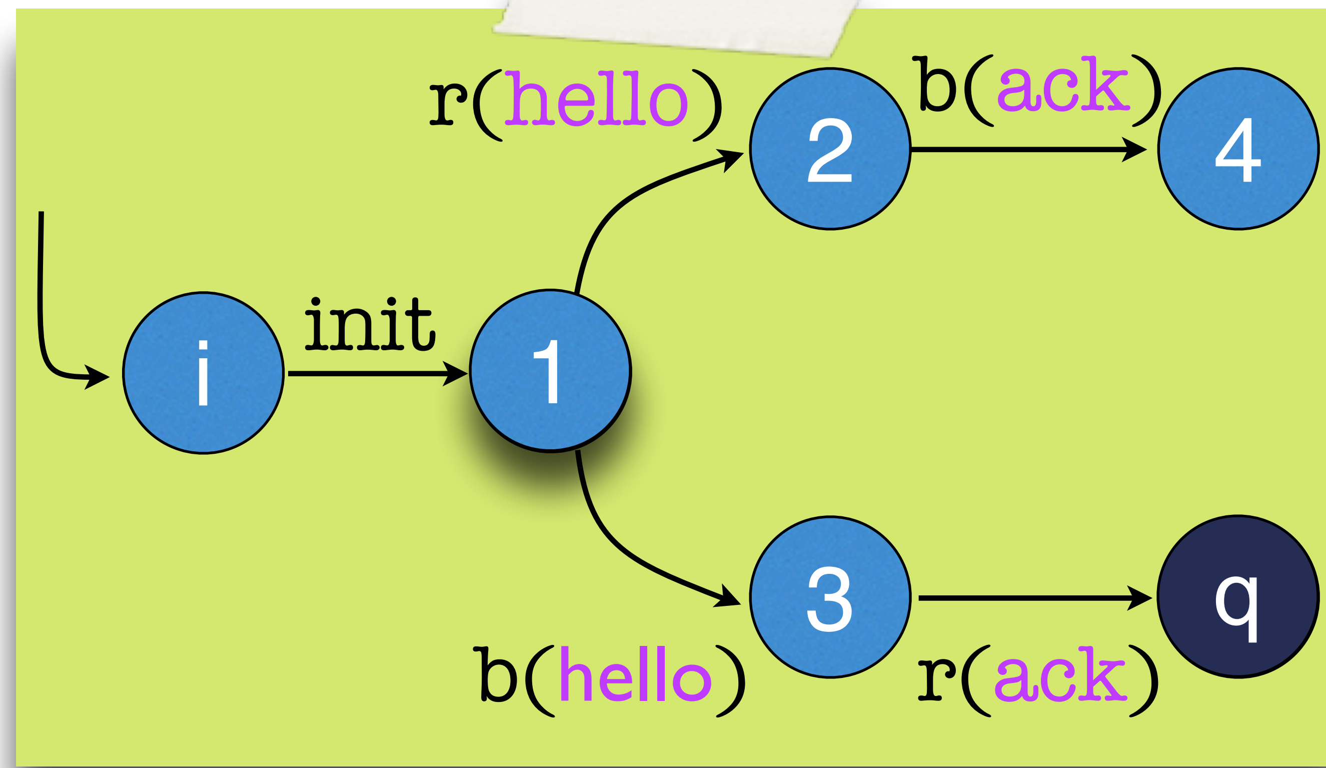
Directed Acyclic

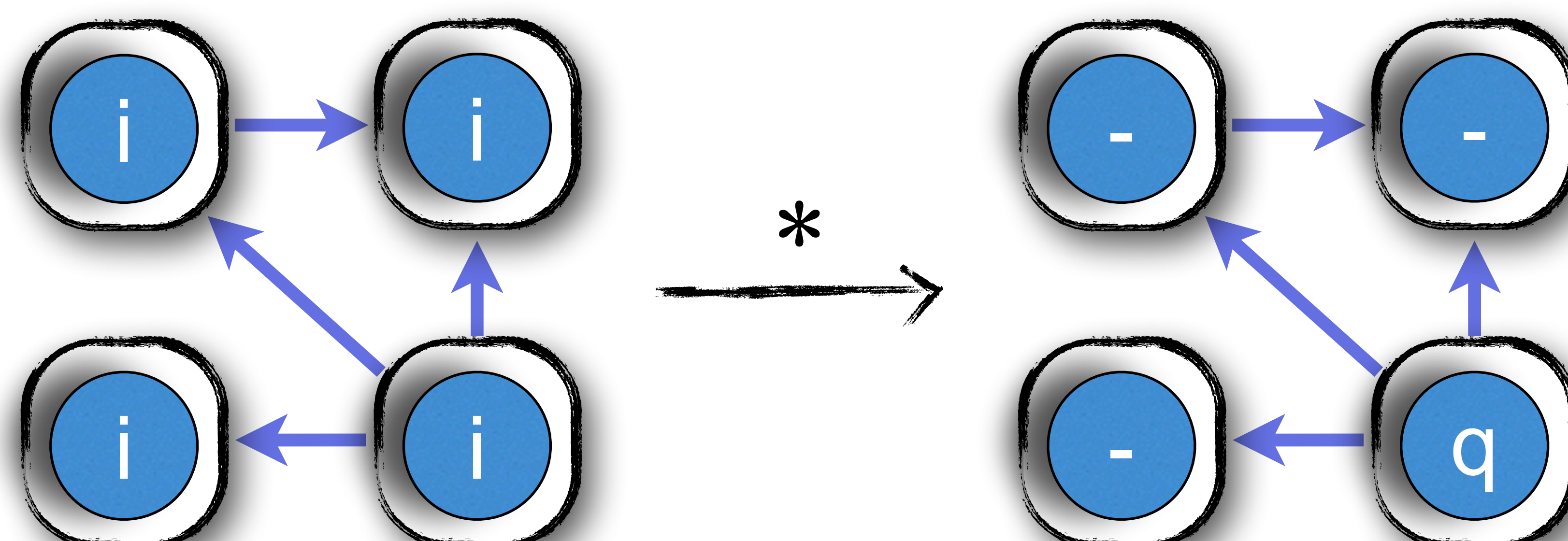
Control State Reachability (COVER)

Given

- Process P
- Control State q

Process





Control State Reachability (COVER)

Is still Undecidable

Control State Reachability (COVER)

Is still Undecidable

Given A, B and T, is there k

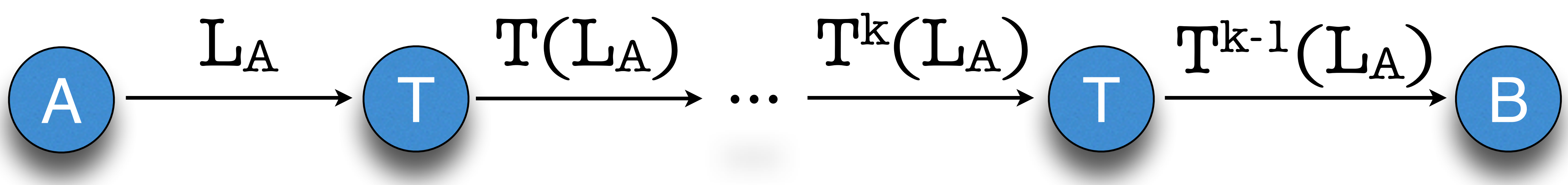
$$T^k(L_A) \cap L_B \neq \emptyset$$

Control State Reachability (COVER)

Is still Undecidable

Given A, B and T, is there k

$$T^k(L_A) \cap L_B \neq \emptyset$$



Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

Directed Acyclic

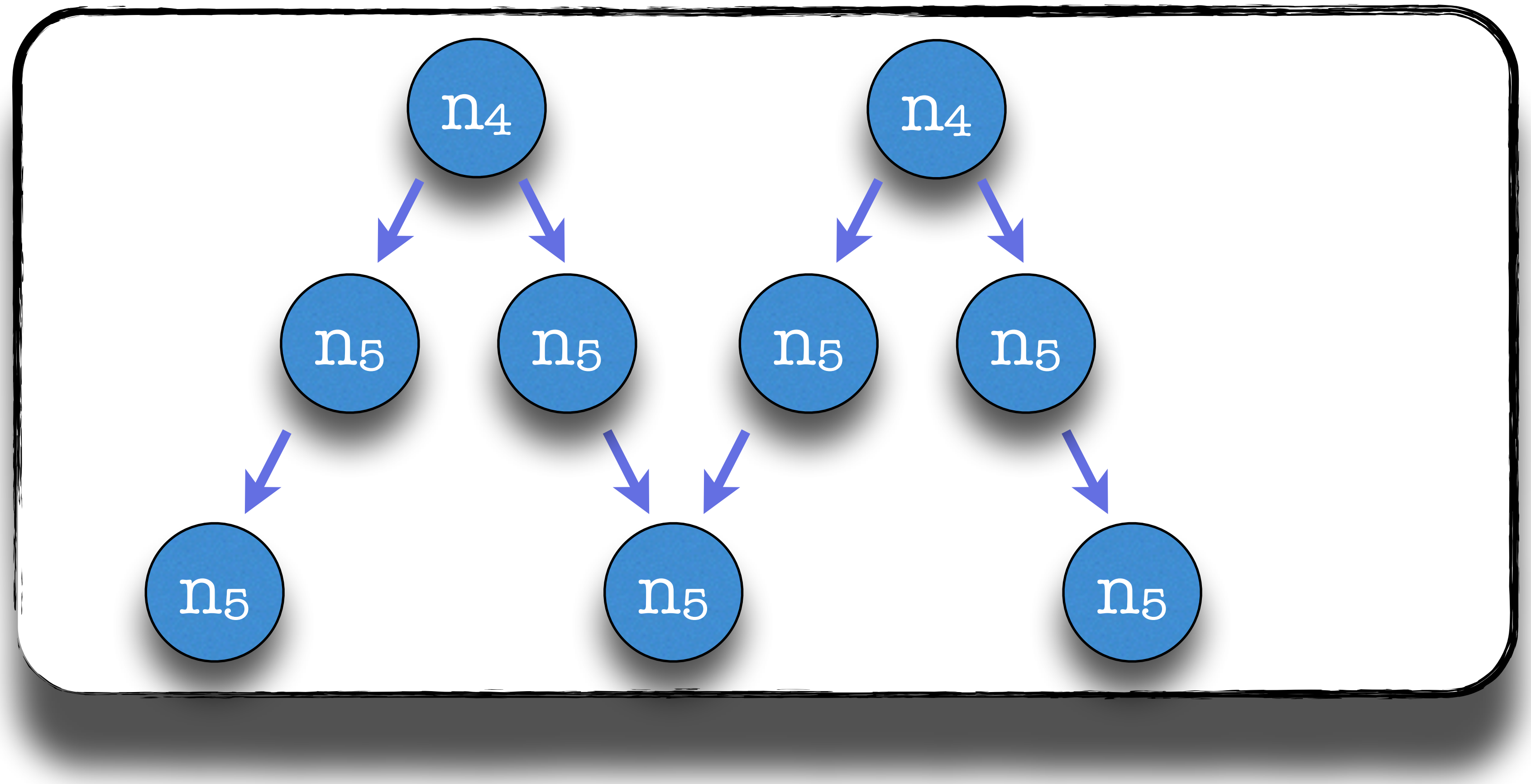
Directed Acyclic

Control State Reachability (COVER)

Is still Undecidable

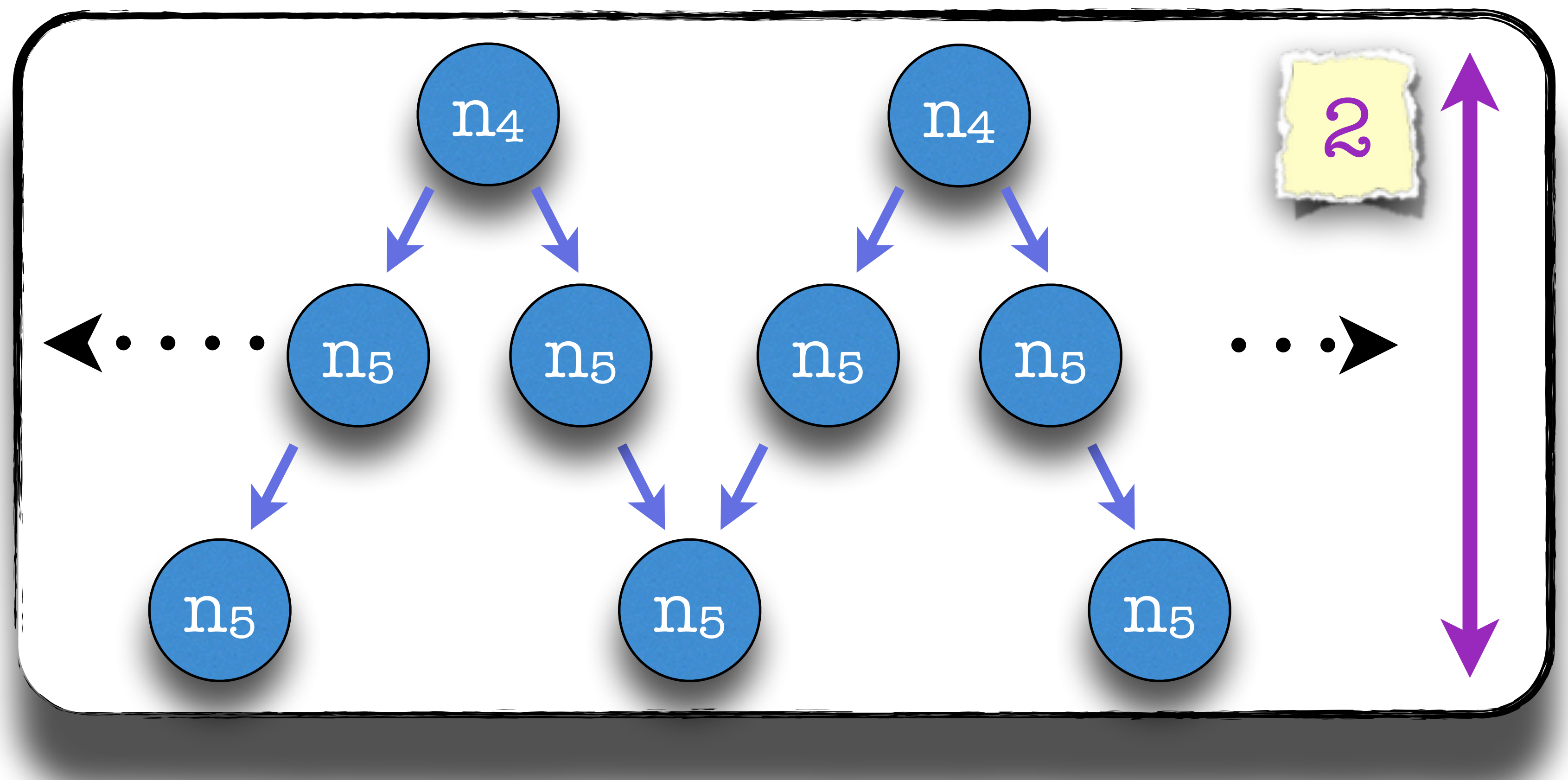
Bounded Depth Control State Reachability

Bounded Depth Control State Reachability



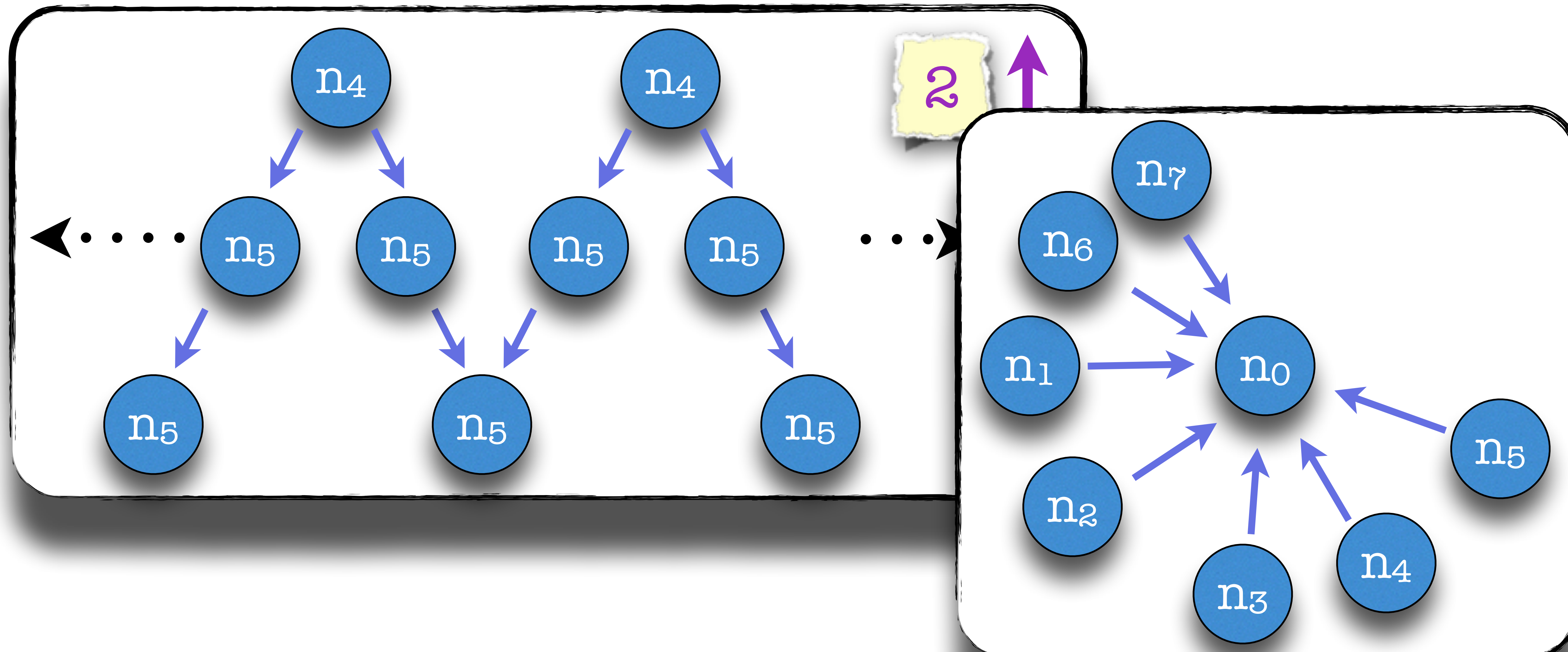
Directed Acyclic

Bounded Depth **Control State Reachability**



Directed Acyclic

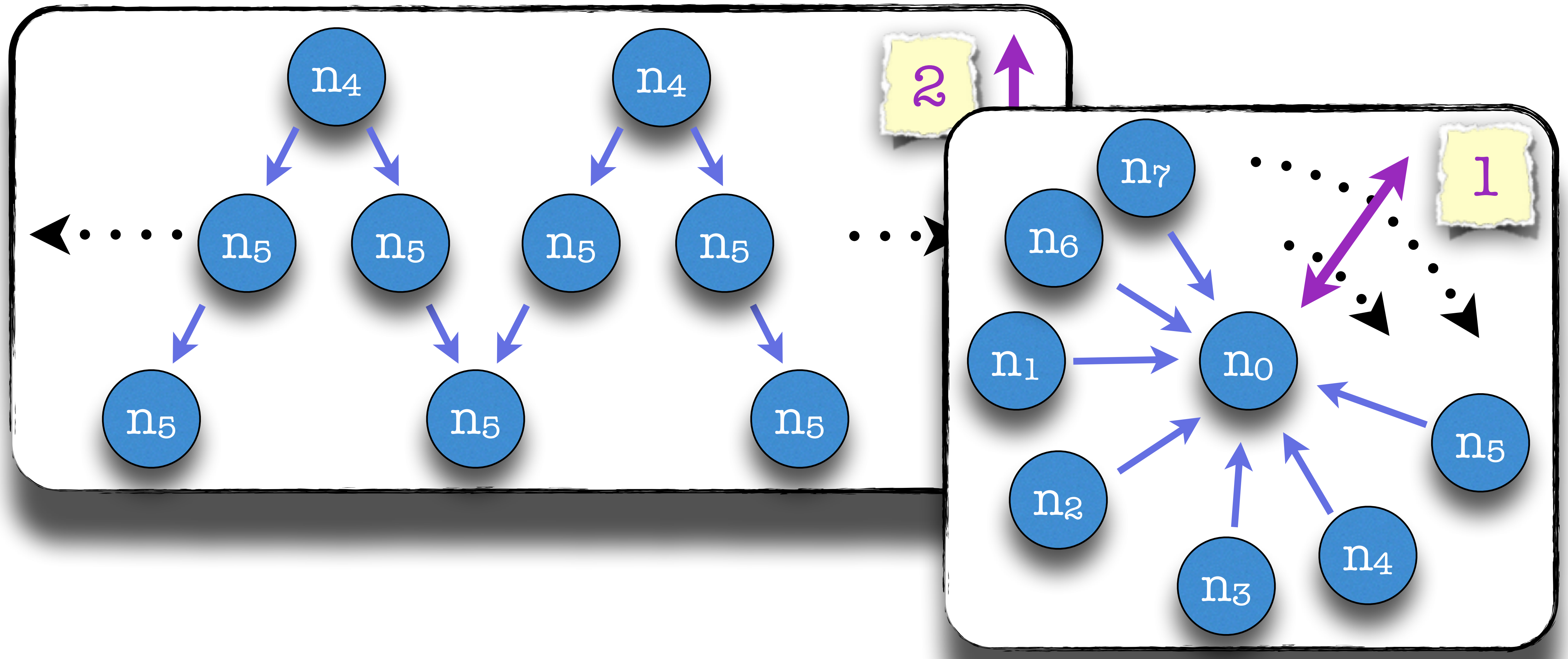
Bounded Depth Control State Reachability



Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

Bounded Depth Control State Reachability



Directed Acyclic

- Motivation
- Reachability
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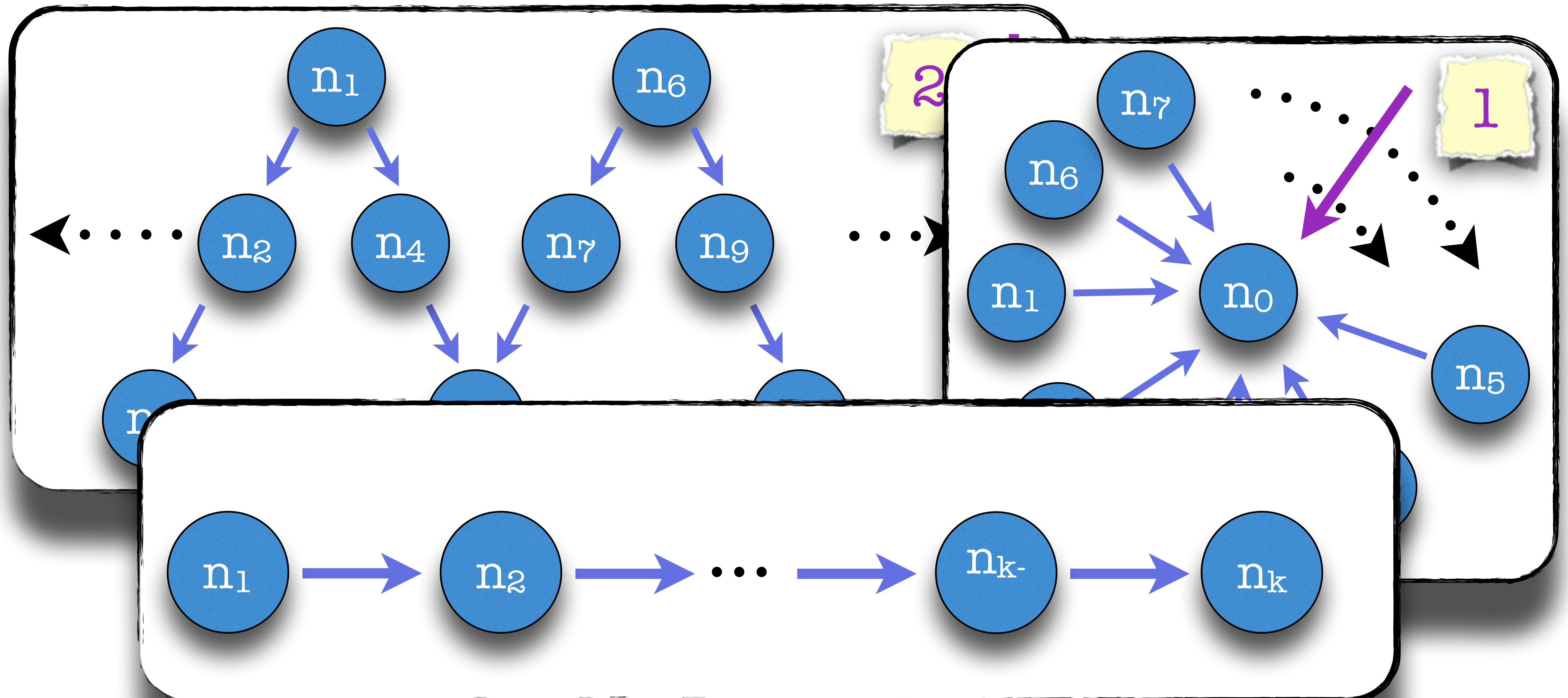
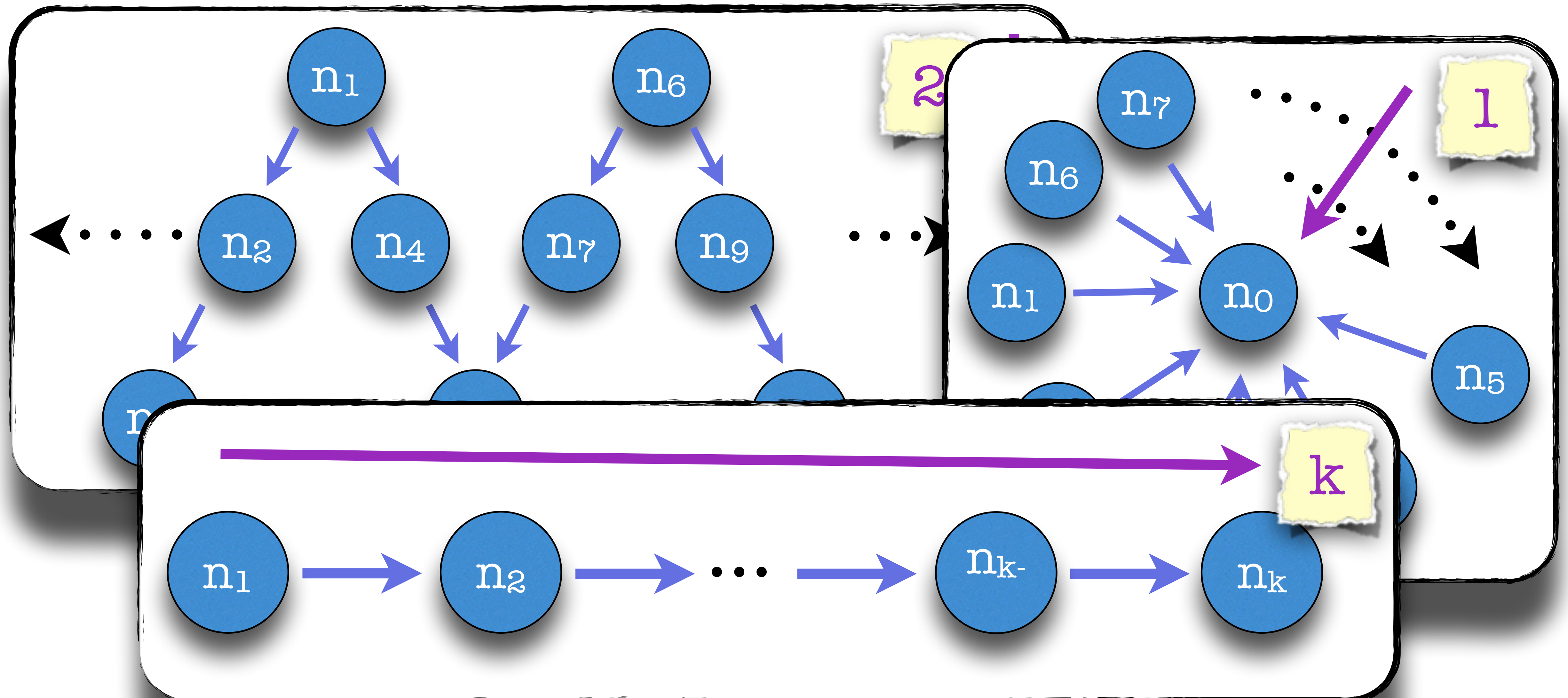
Bounded Depth Control State Reachability



Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

k Bounded Depth Control State Reachability



Directed Acyclic

k Bounded Depth Control State Reachability

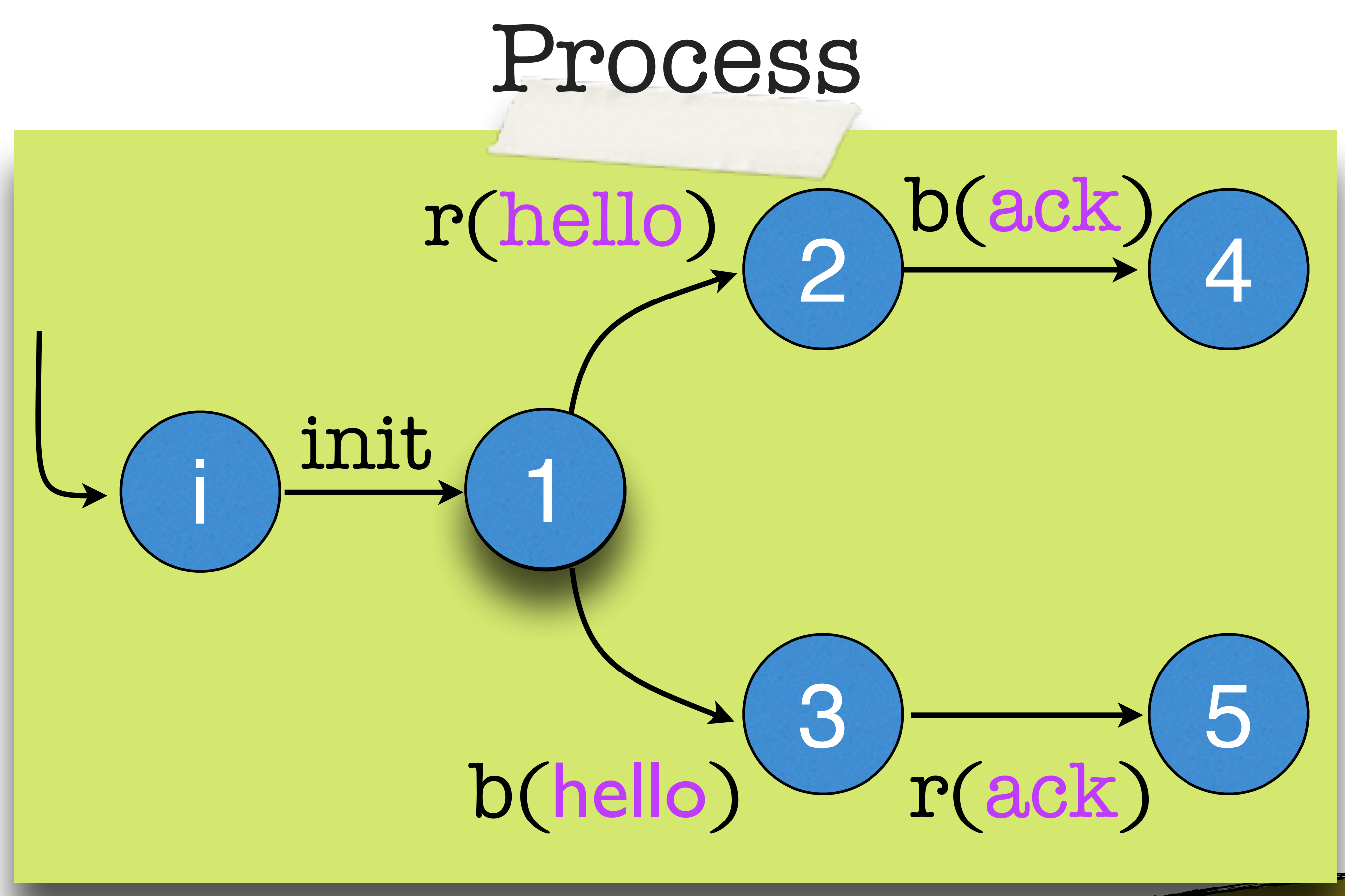
Given

Directed Acyclic

k Bounded Depth Control State Reachability

Given

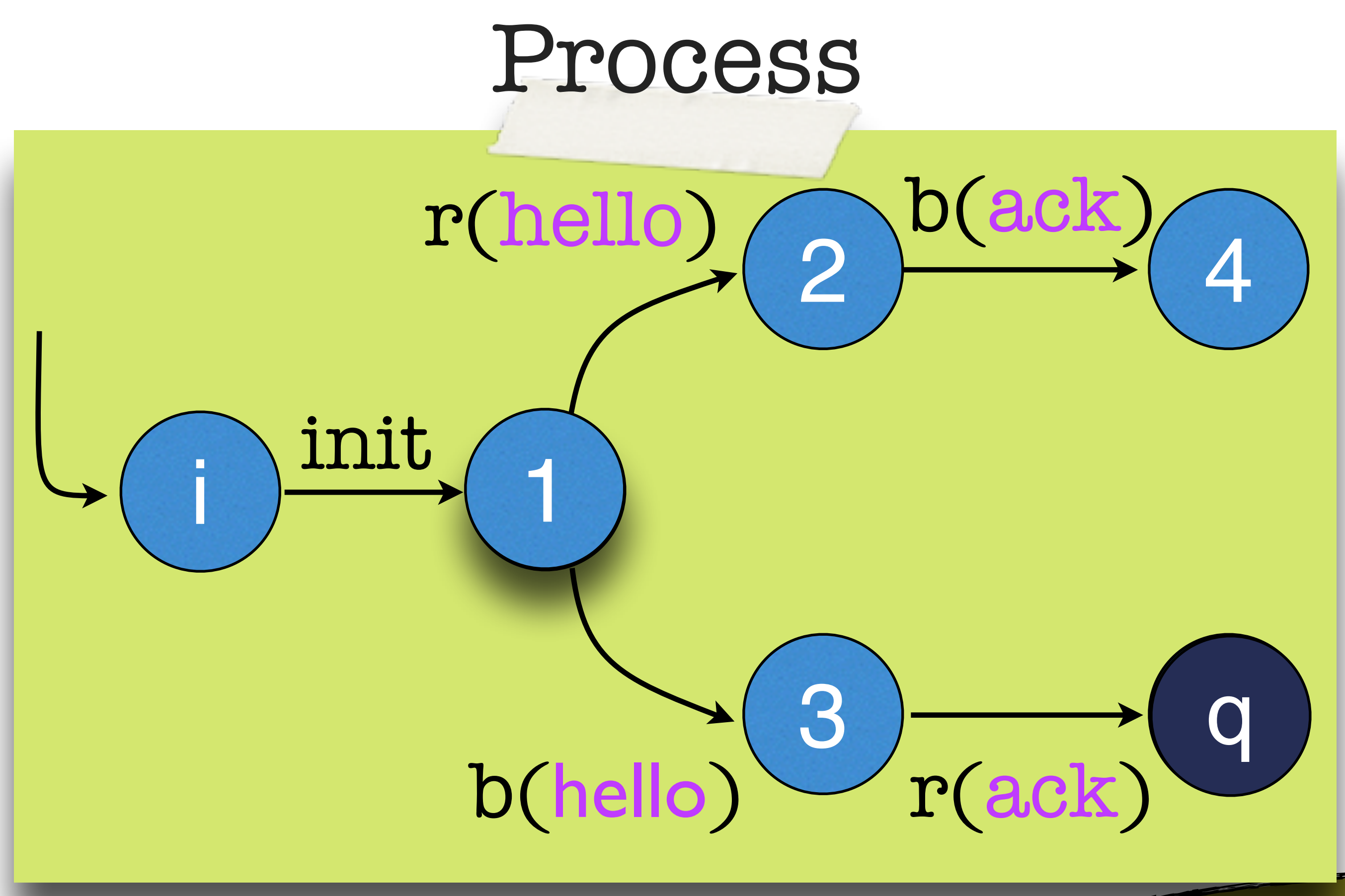
- Process P



Directed Acyclic

k Bounded Depth Control State Reachability

Given
- Process P
- Control State q



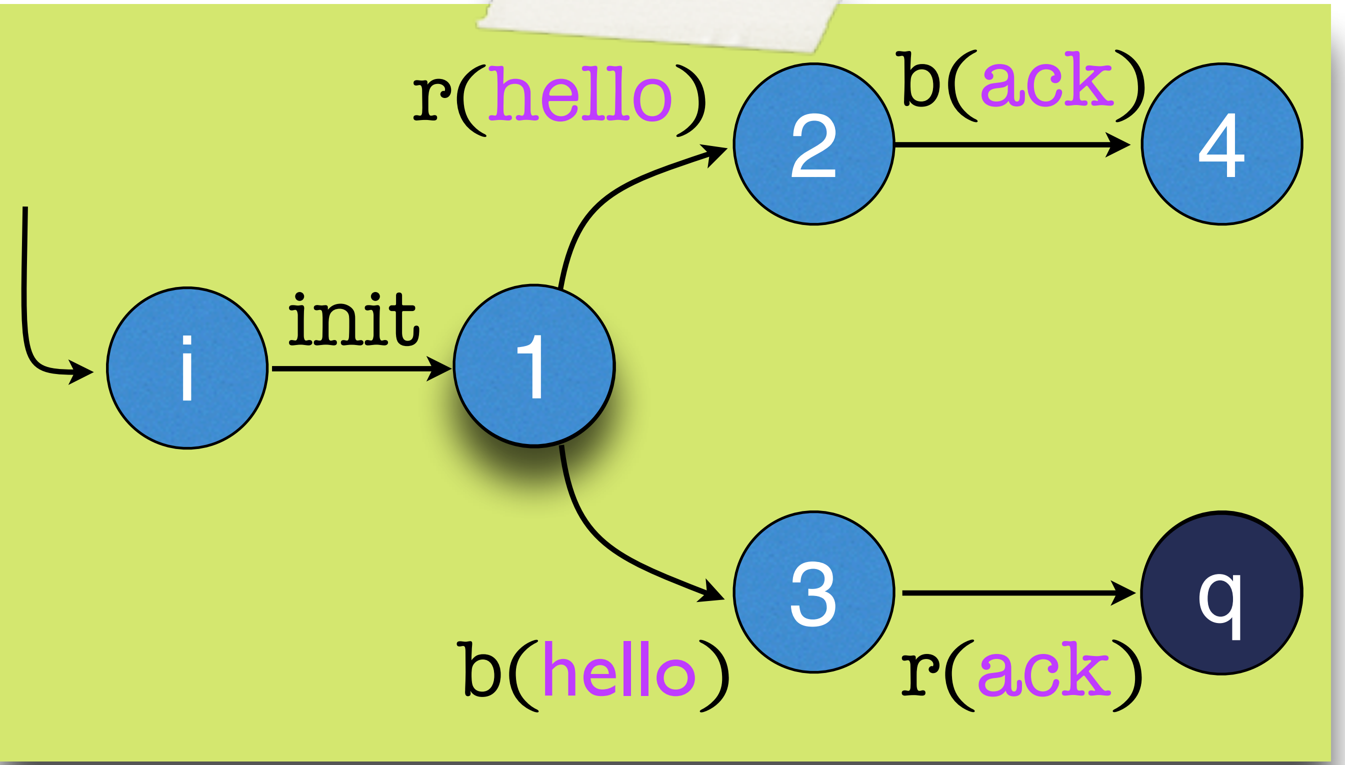
Directed Acyclic

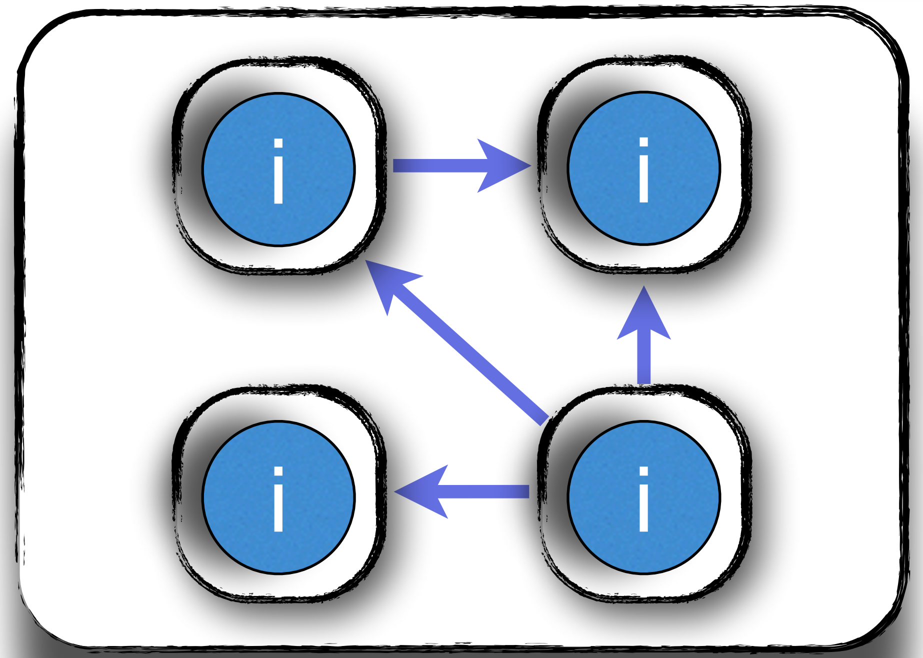
- Motivation
- Reachability
- Bounded Depth Reachability

k Bounded Depth
Control State Reachability
(BOUNDED-COVER)

Given
- Process P
- Control State q

Process





Directed Acyclic

- Motivation
- Reachability
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k Bounded Depth

Control State Reachability

(BOUNDED-COVER)

Given
- Process P
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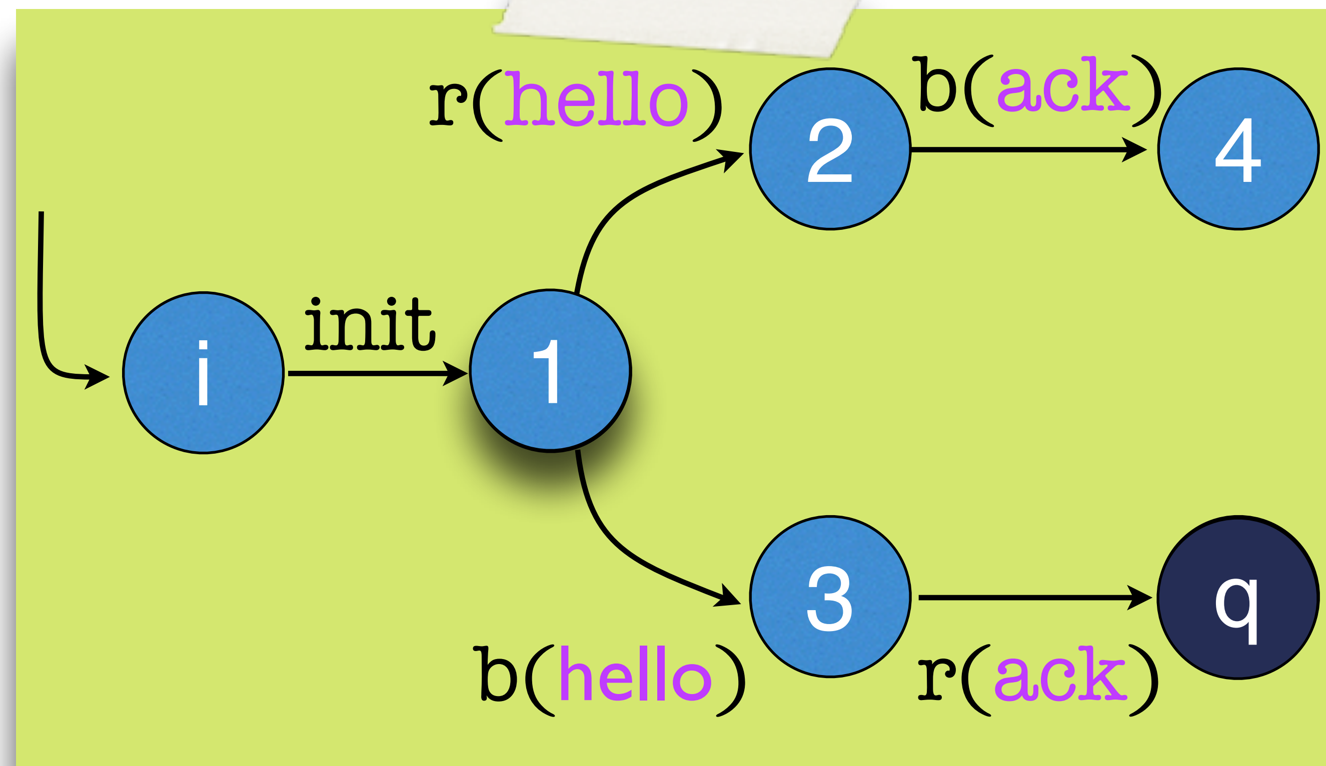
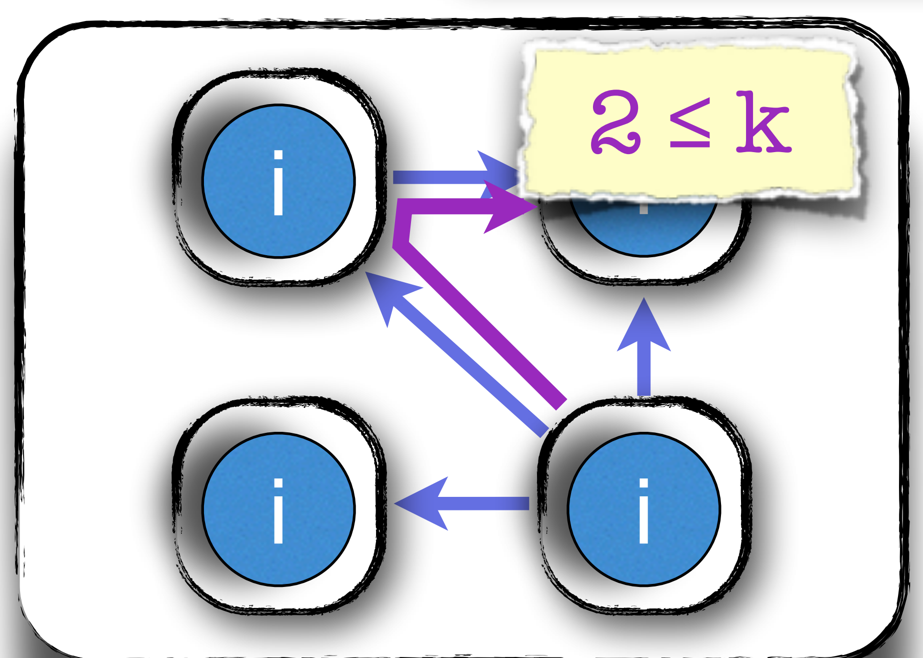
Process





Directed Acyclic

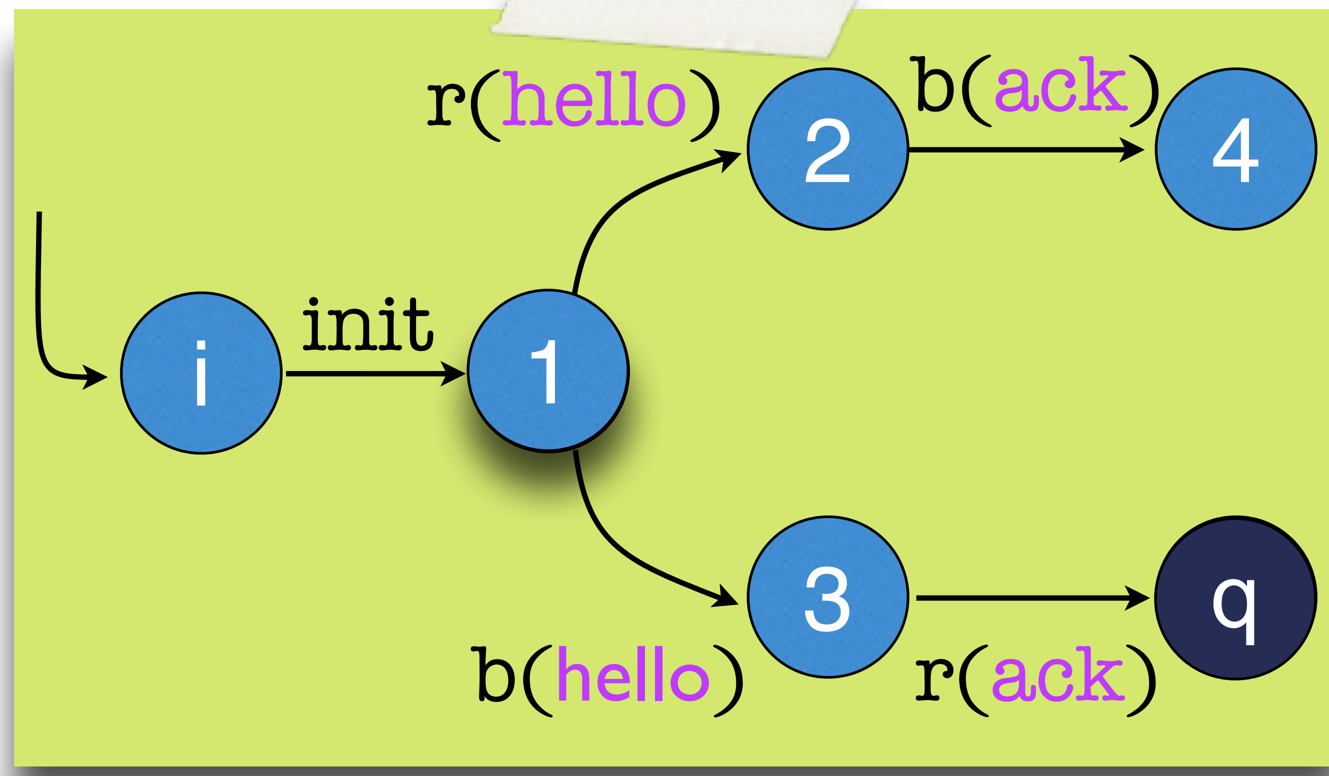
k **Bounded Depth**

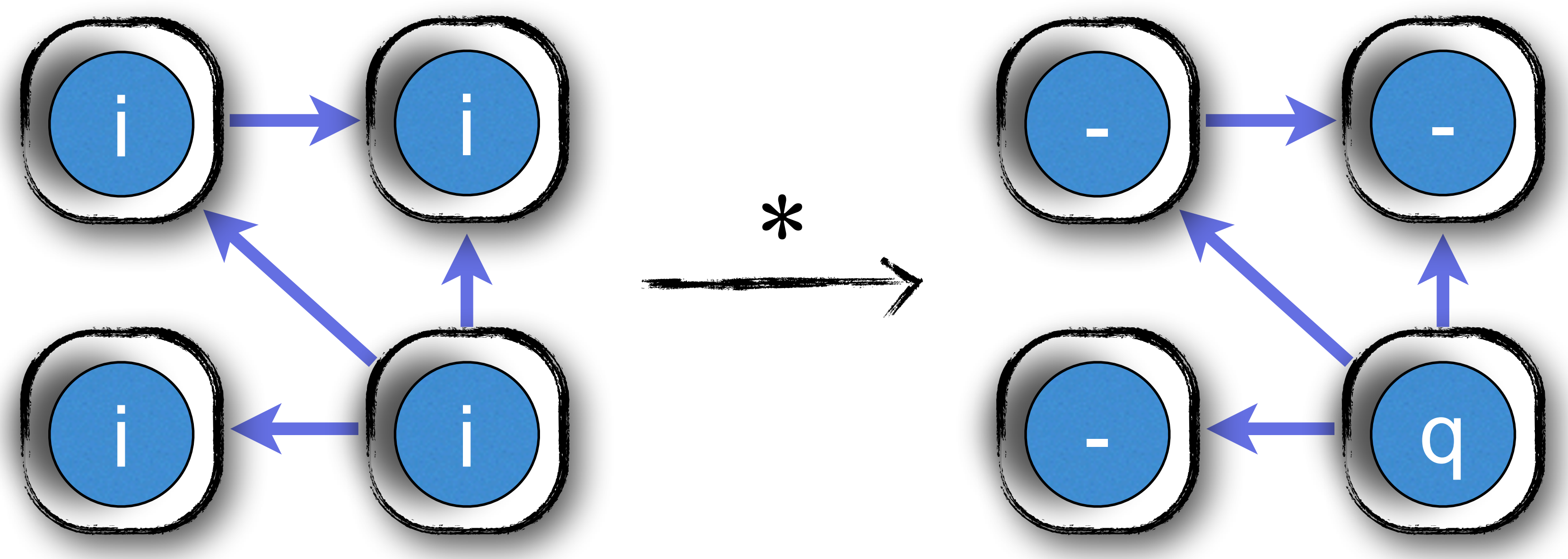
Control State Reachability

(BOUNDED-COVER)

Given
- Process P
- Control State q

Process





Directed Acyclic

(BOUNDED-COVER) DECIDABLE

Directed Acyclic

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

(2)Reduce **(BOUNDED-COVER)** **(TREE-BOUNDED-COVER)**

(3)Define an ordering on configurations

Directed Acyclic

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
- $\longrightarrow$: Monotonic wrt. $\sqsubseteq$

Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

(BOUNDED-COVER) DECIDABLE

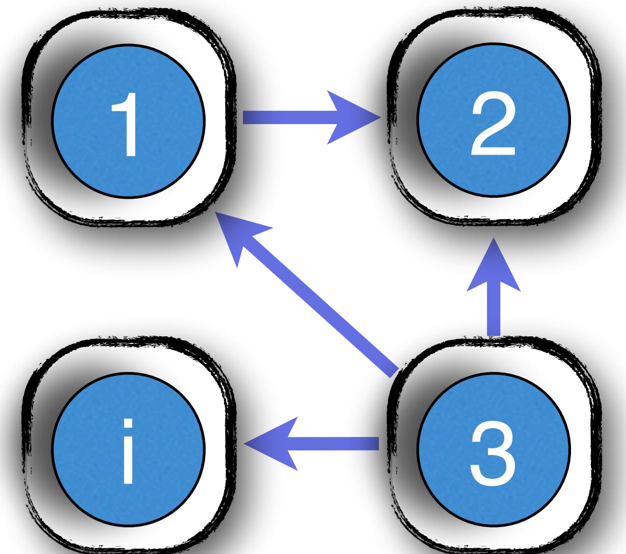
Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
- $\longrightarrow$: Monotonic wrt. $\sqsubseteq$

C_0



(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
- $\longrightarrow$: Monotonic wrt. $\sqsubseteq$

$\forall\ (C_i)_{i\geq 0}$

$$C_0 \longrightarrow C_1 \longrightarrow \cdots$$

Directed Acyclic

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
- $\longrightarrow$: Monotonic wrt. $\sqsubseteq$

$$\forall\ (C_i)_{i \geq 0}$$

$$C_0 \longrightarrow C_1 \longrightarrow \cdots$$

$$\exists\ i < j\ ;\ C_i \sqsubseteq C_j$$

Directed Acyclic

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
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Directed Acyclic

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
- $\longrightarrow$: Monotonic wrt. $\sqsubseteq$

c_3

$\sqcup\!\mid$

$c_1 \longrightarrow c_2$

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
- $\longrightarrow$: Monotonic wrt. $\sqsubseteq$

$C_3 \qquad C_4$

$\sqsupseteq$

$C_1 \longrightarrow C_2$

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
- $\longrightarrow$: Monotonic wrt. $\sqsubseteq$

$$\begin{array}{ccc} c_3 & & c_4 \\ \sqsupseteq & & \sqsupseteq \\ c_1 & \longrightarrow & c_2 \end{array}$$

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
- $\longrightarrow$: Monotonic wrt. $\sqsubseteq$

$$\begin{array}{ccc} c_3 & \longrightarrow & c_4 \\ \sqsupseteq & & \sqsupseteq \\ c_1 & \longrightarrow & c_2 \end{array}$$

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
- $\longrightarrow$: Monotonic wrt. $\sqsubseteq$

WSTS framework Algorithm:

Directed Acyclic

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
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WSTS framework Algorithm:

- Symbolic Representation of Infinite Sets

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

Pre-requisites

- $\sqsubseteq$ is a Well-Quasi Order
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WSTS framework Algorithm:

- Symbolic Representation of Infinite Sets
- Backward Analysis

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

(2)Reduce **(BOUNDED-COVER)** **(TREE-BOUNDED-COVER)**

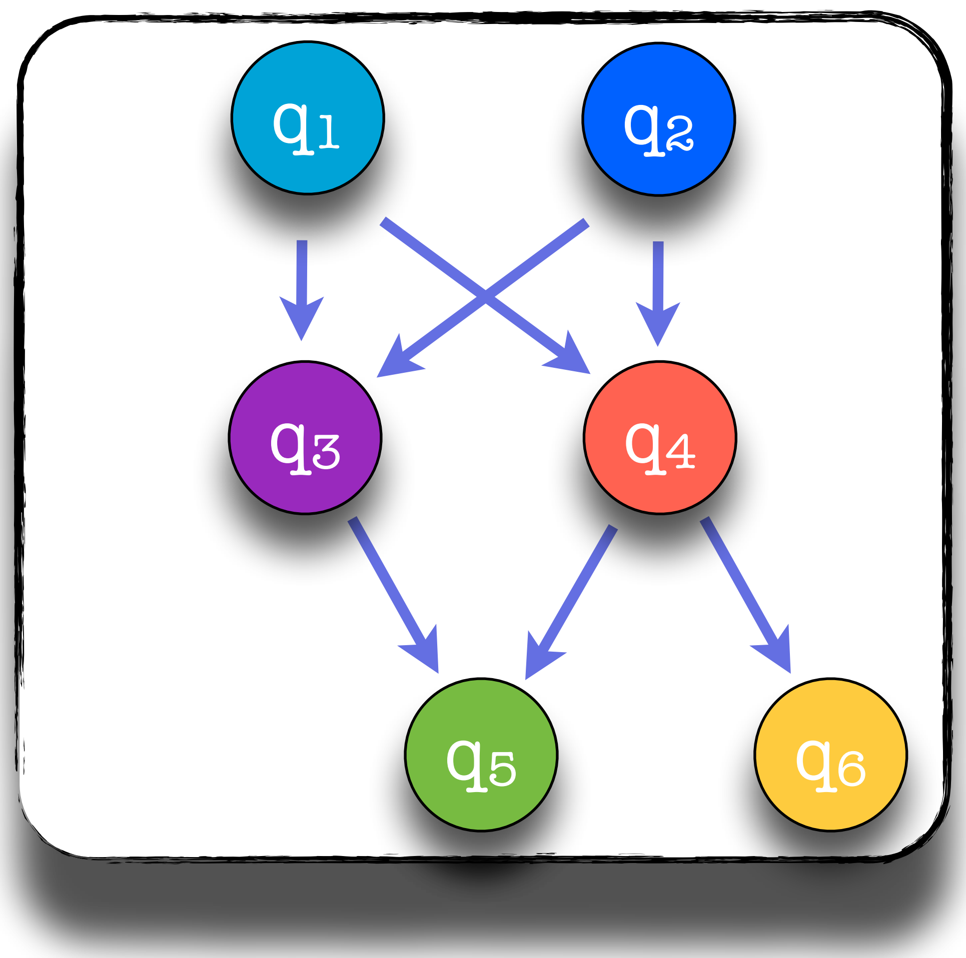
(3)Define an ordering on configurations

Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

(BOUNDED-COVER) DECIDABLE
Theory of Well Structured Transition Systems

(2)Reduce **(BOUNDED-COVER)** **(TREE-BOUNDED-COVER)**



Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

(BOUNDED-COVER) DECIDABLE
Theory of Well Structured Transition Systems

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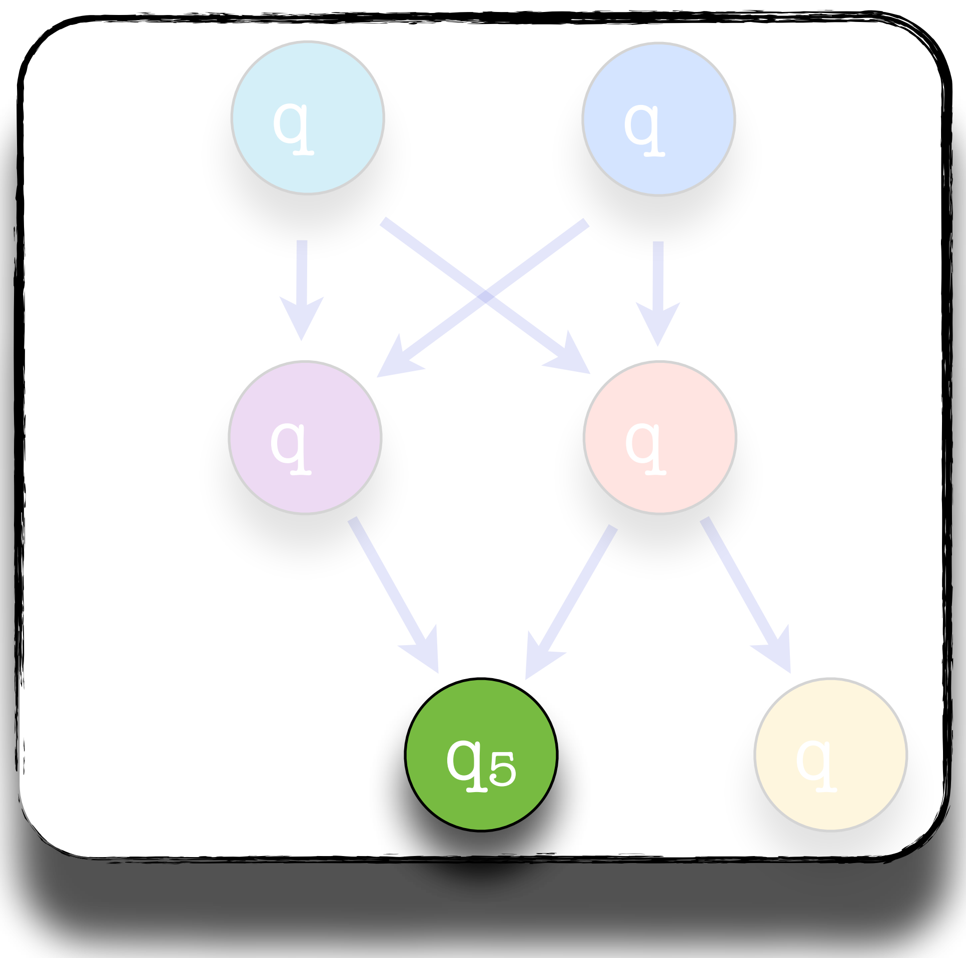

Directed Acyclic

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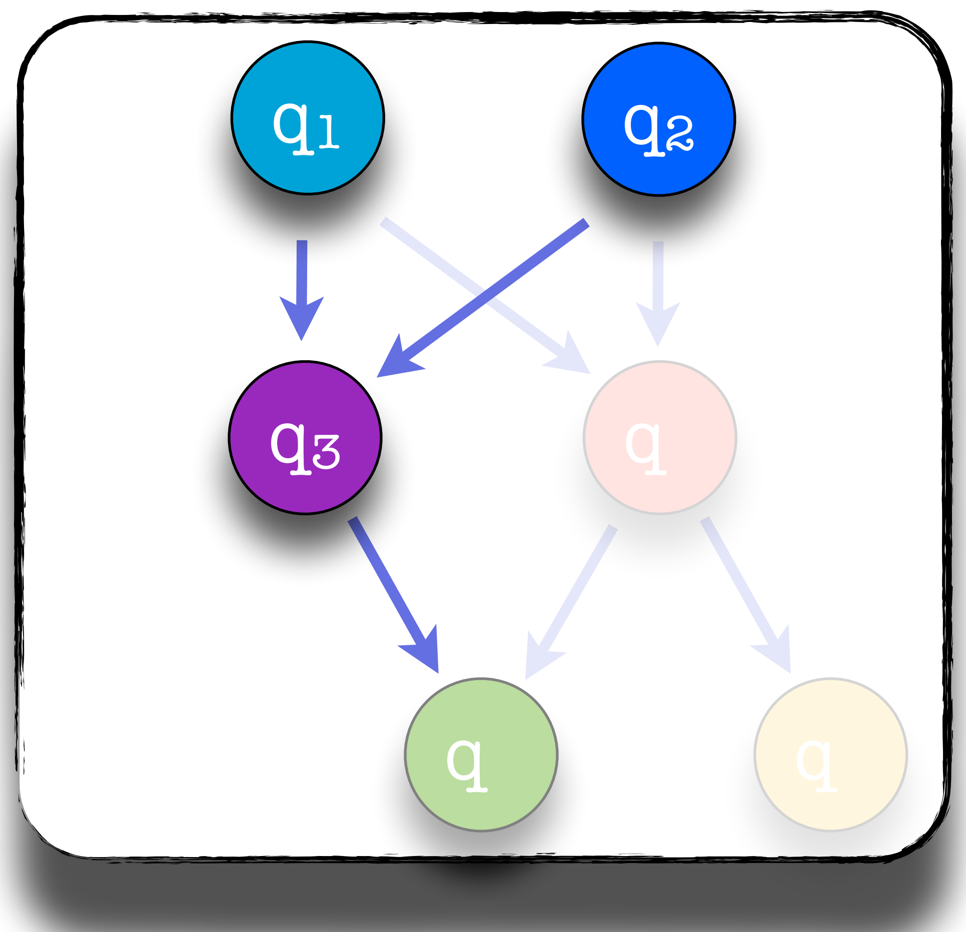

Directed Acyclic

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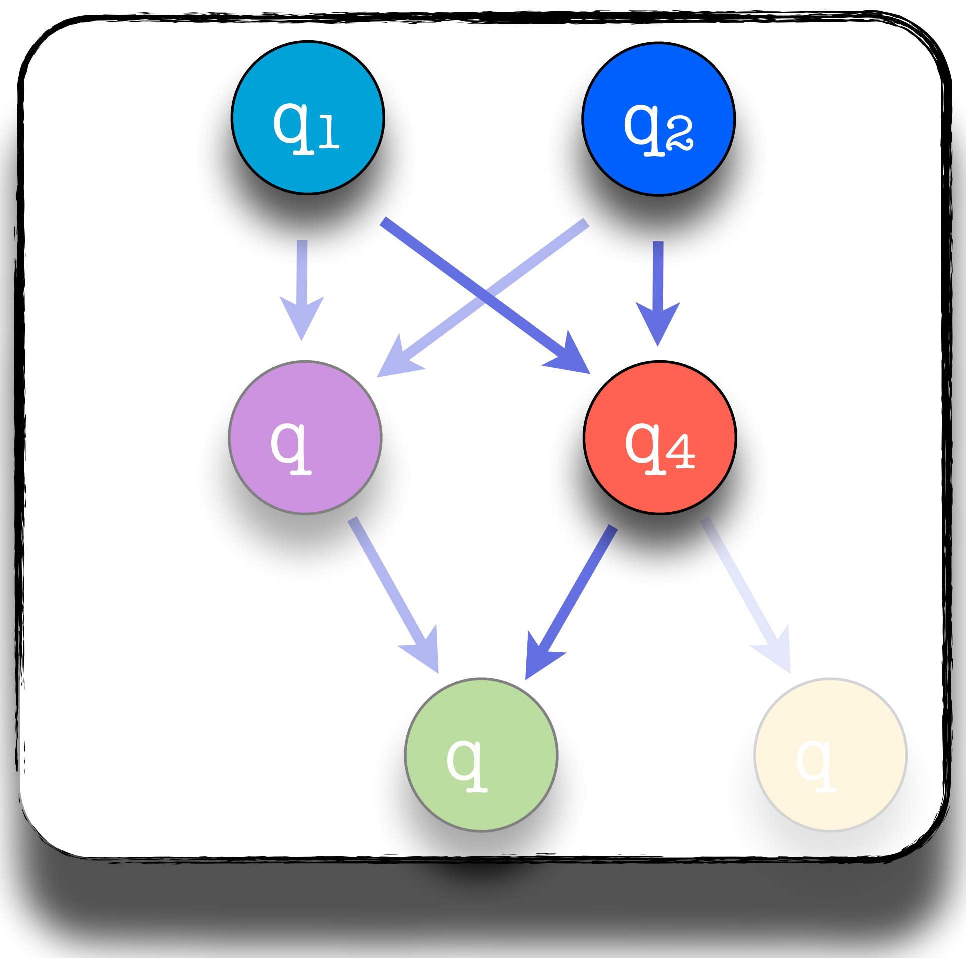

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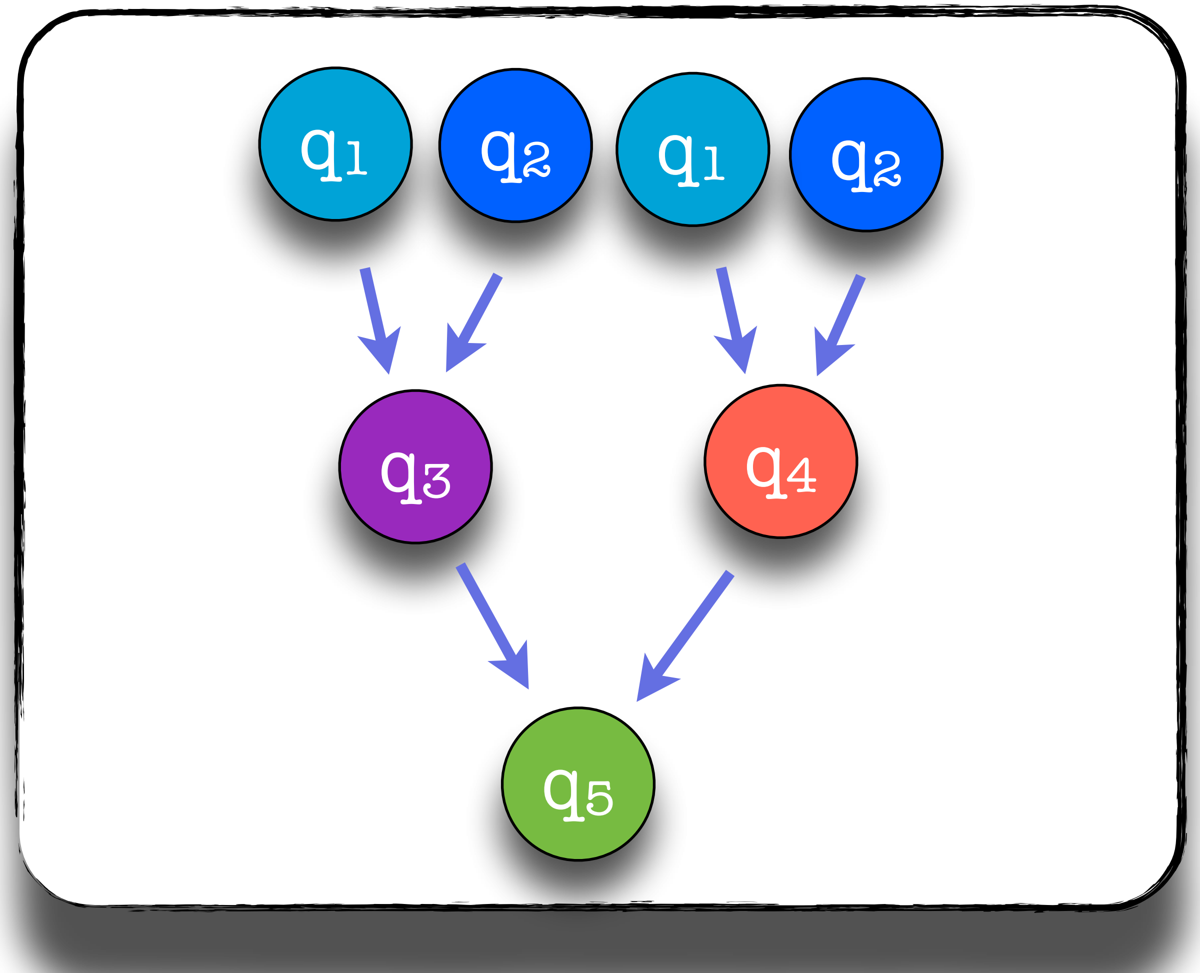

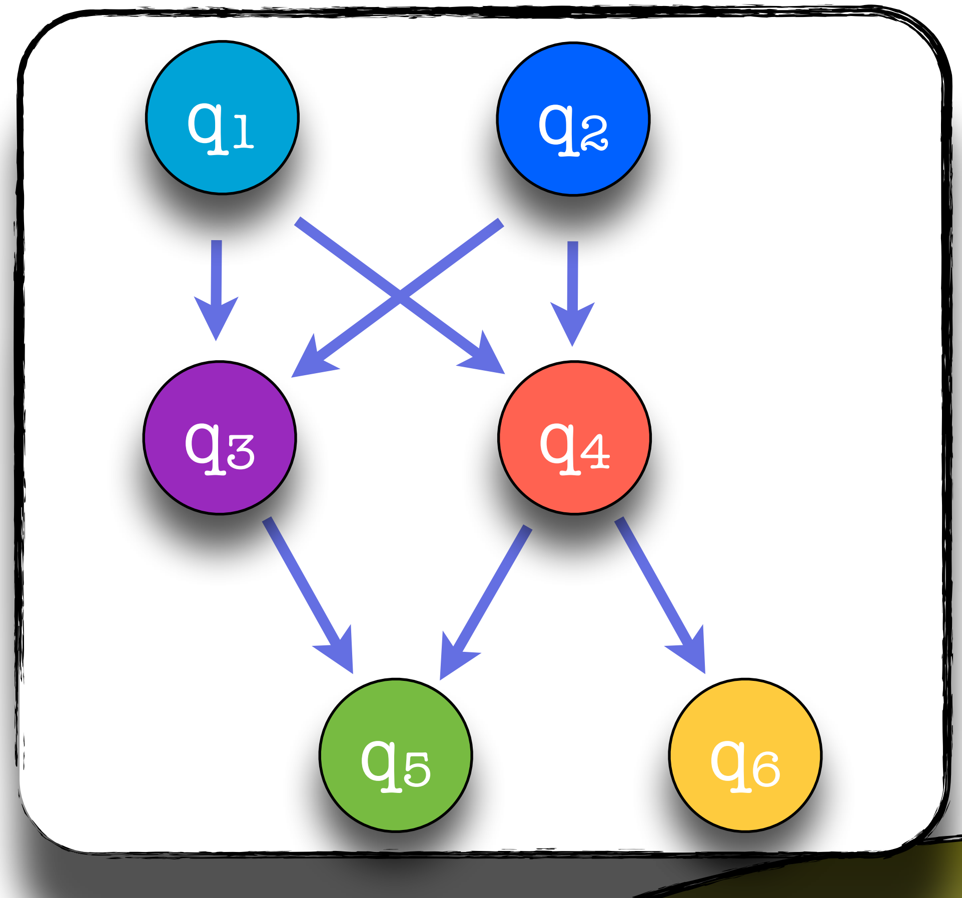

Directed Acyclic

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Theory of Well Structured Transition Systems

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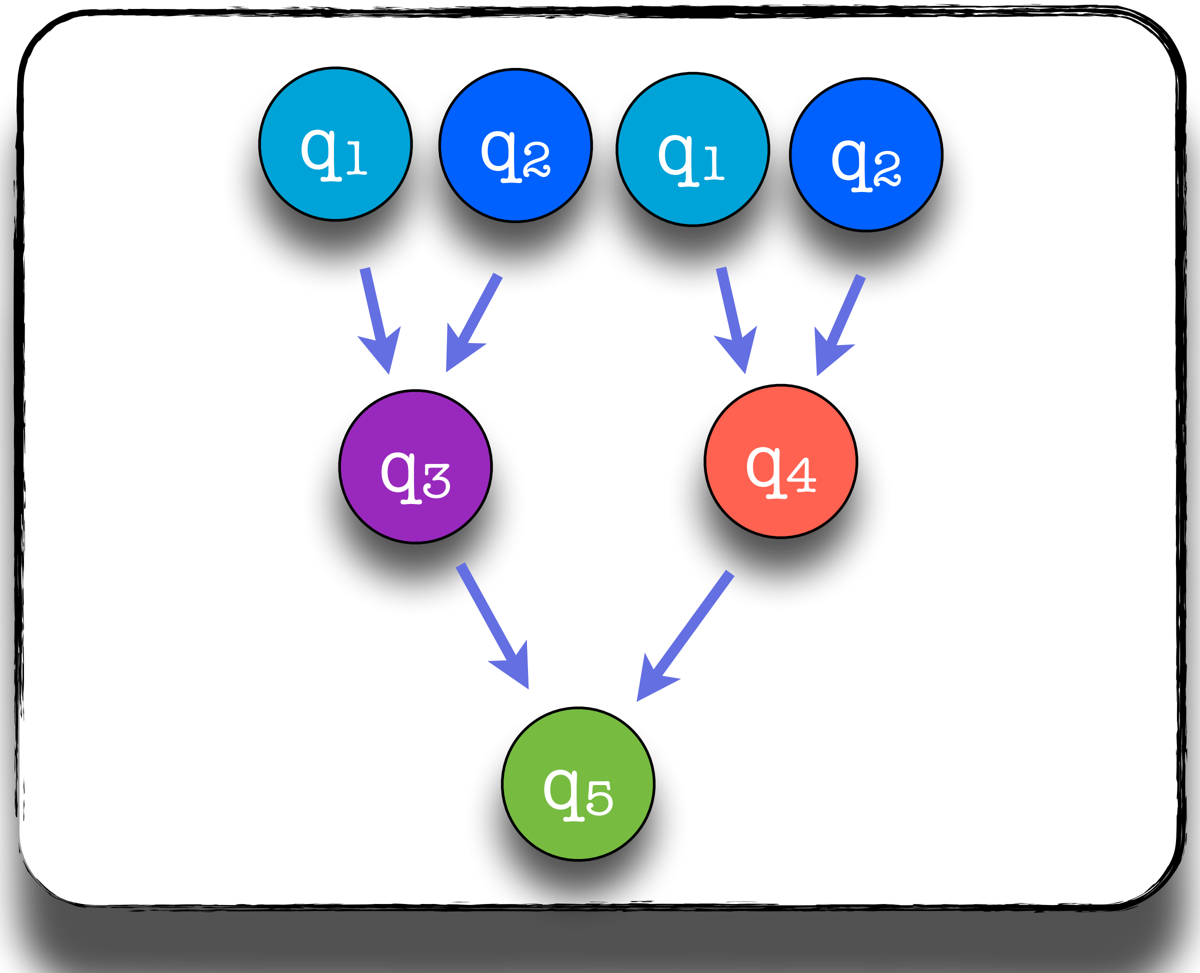

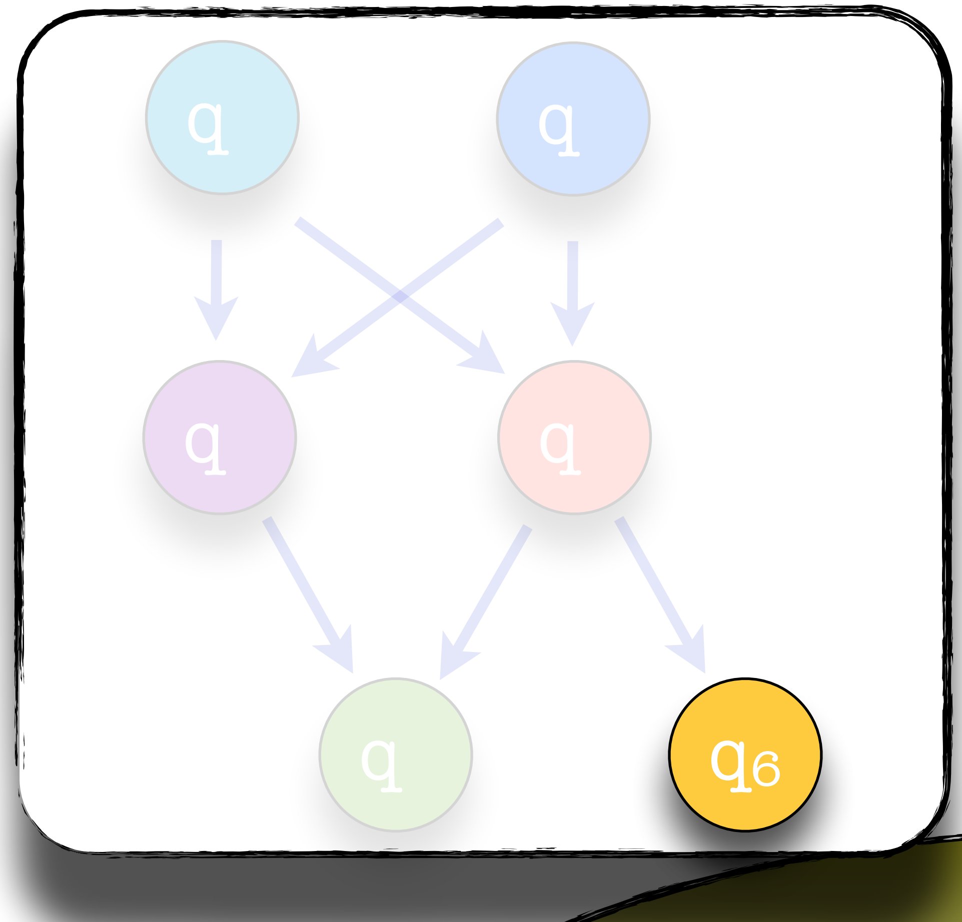

Directed Acyclic

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Theory of Well Structured Transition Systems

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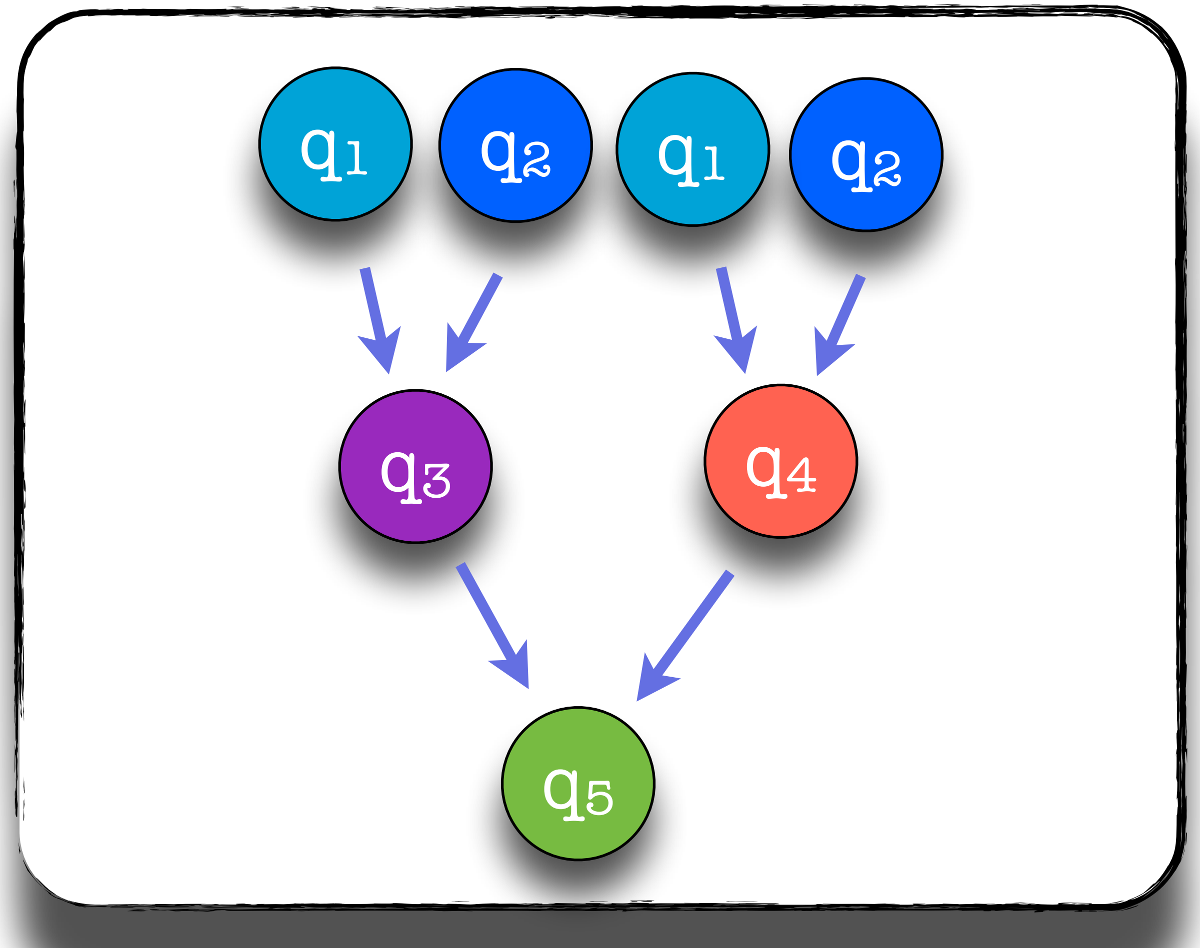

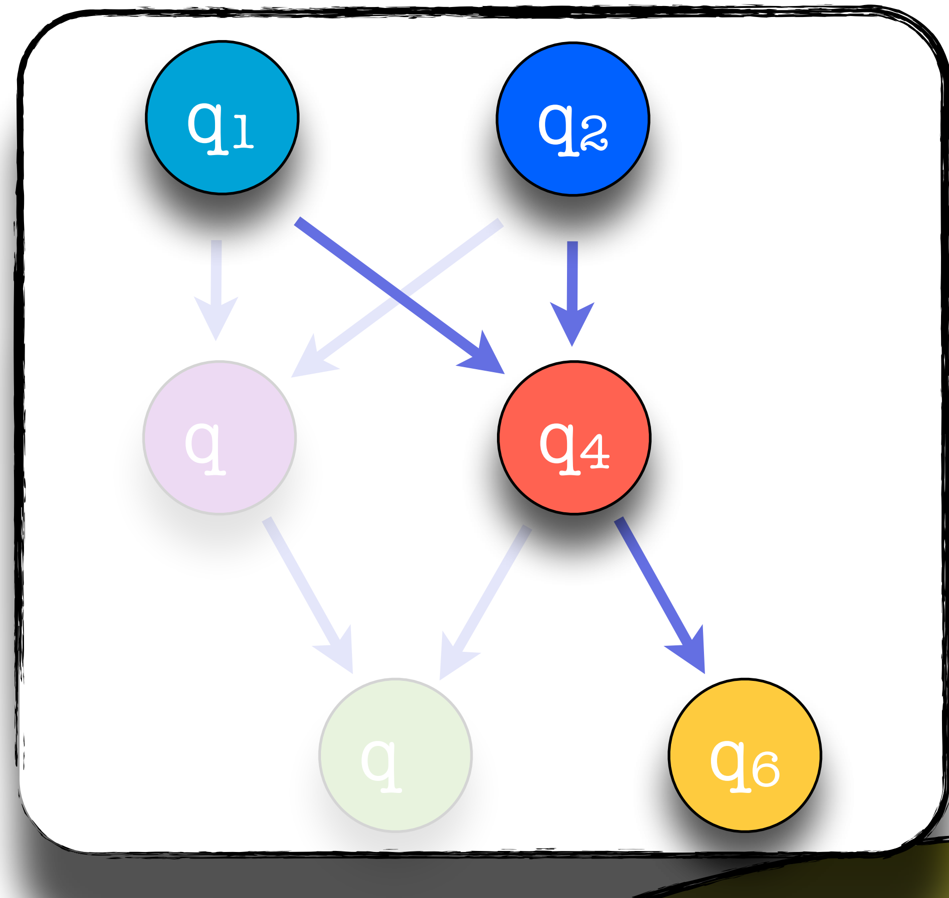

Directed Acyclic

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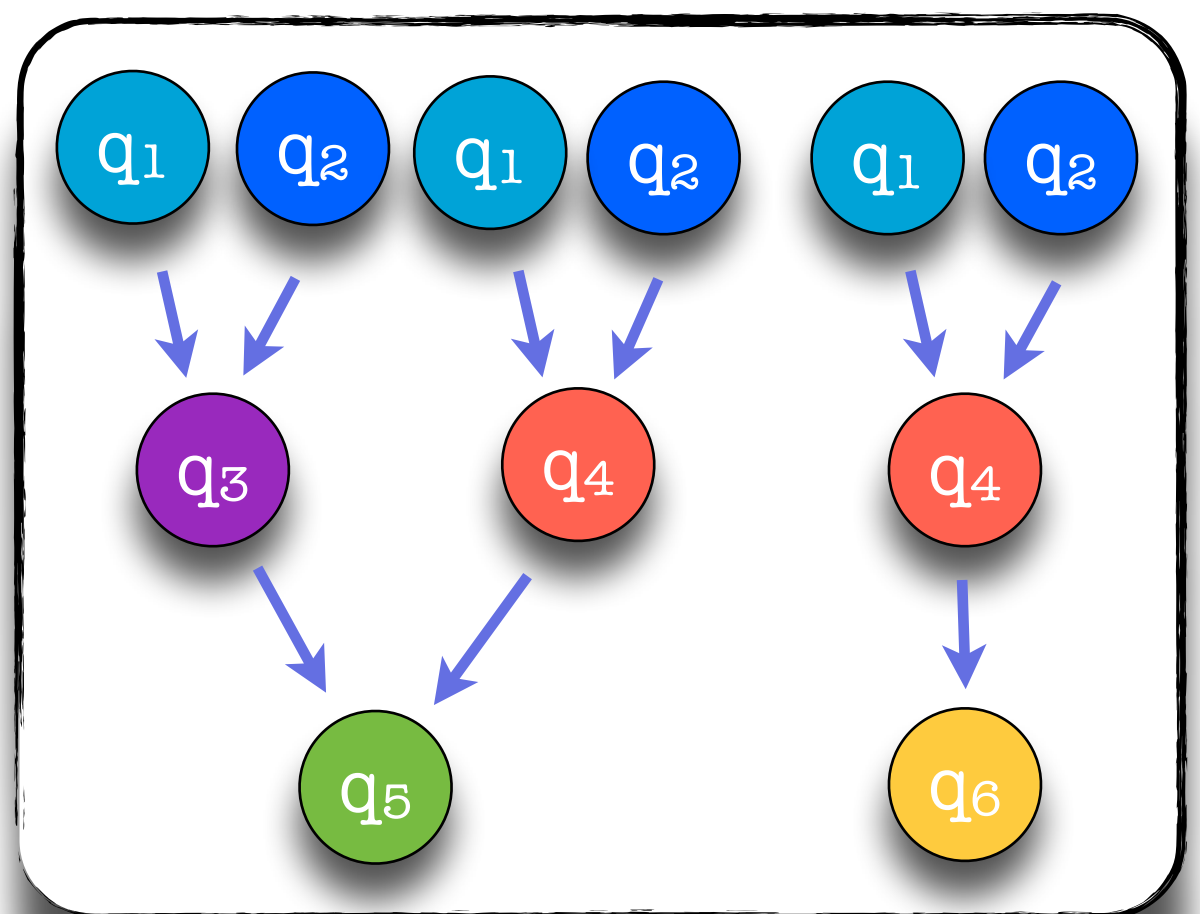

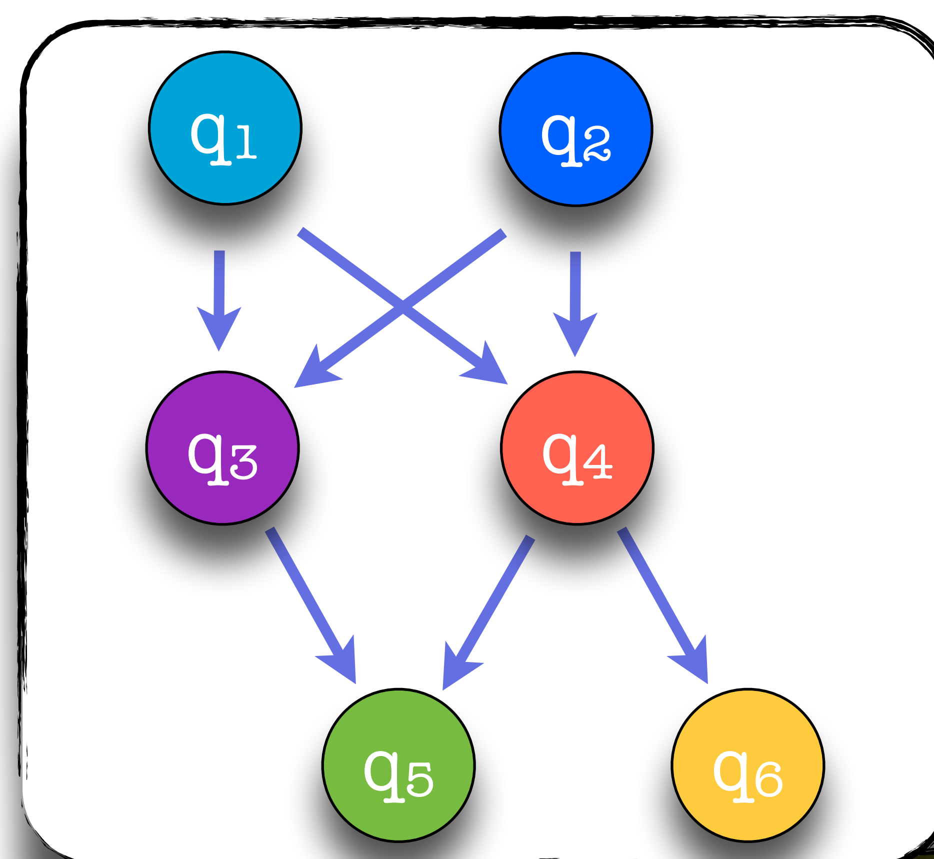

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

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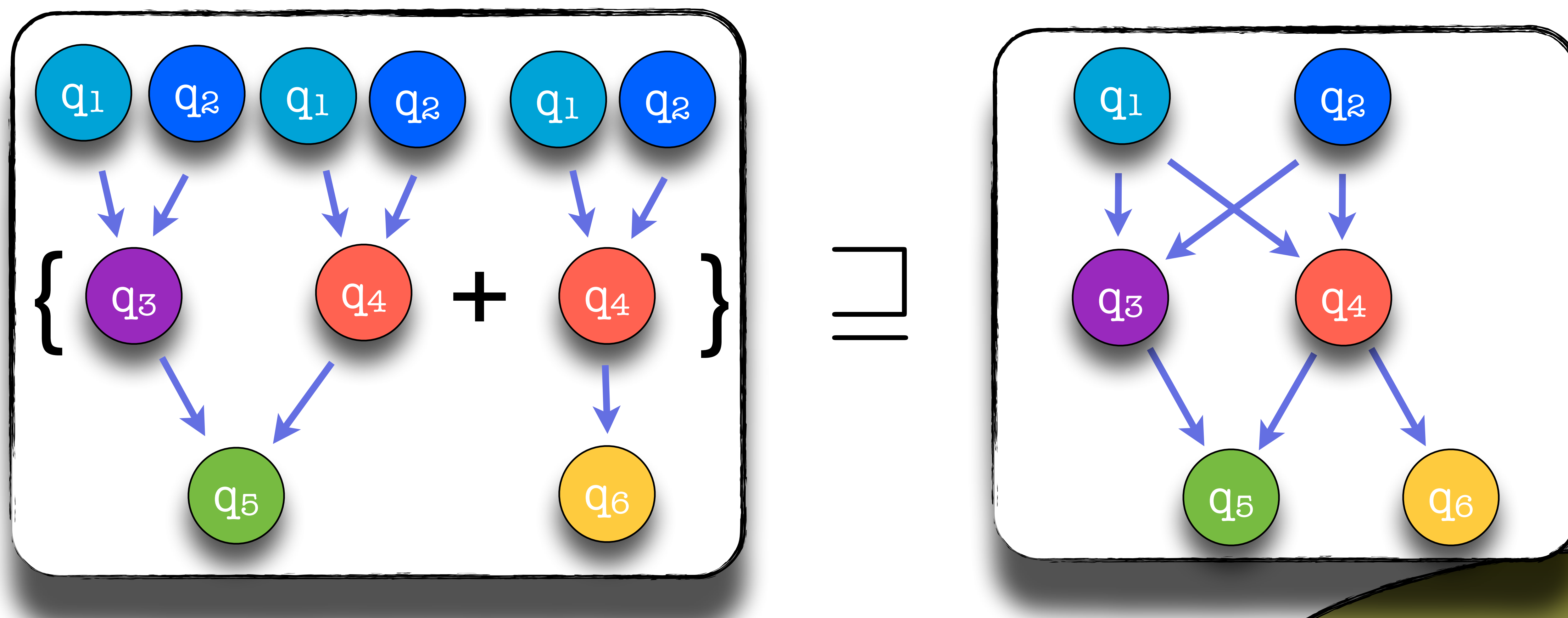

Directed Acyclic

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Theory of Well Structured Transition Systems

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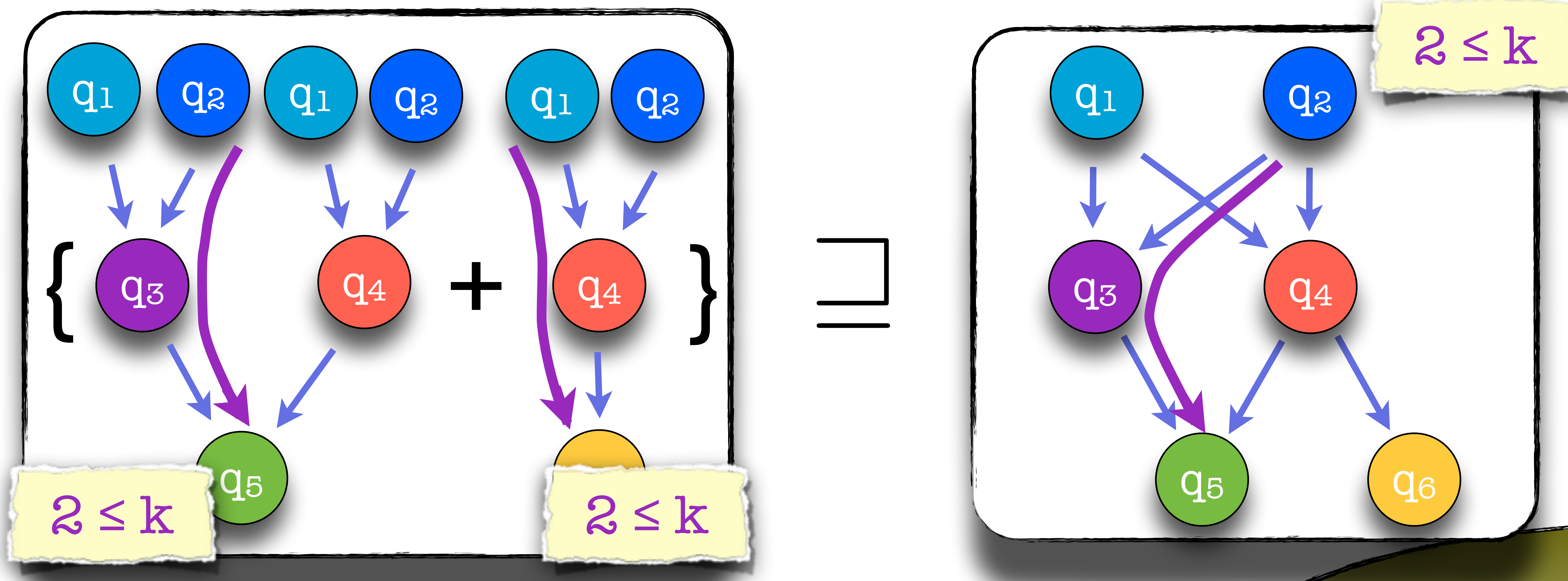


Directed Acyclic

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(1)The WSTS framework

(2)Reduce **(BOUNDED-COVER)** **(TREE-BOUNDED-COVER)**

(3)Define an ordering on configurations

Directed Acyclic

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

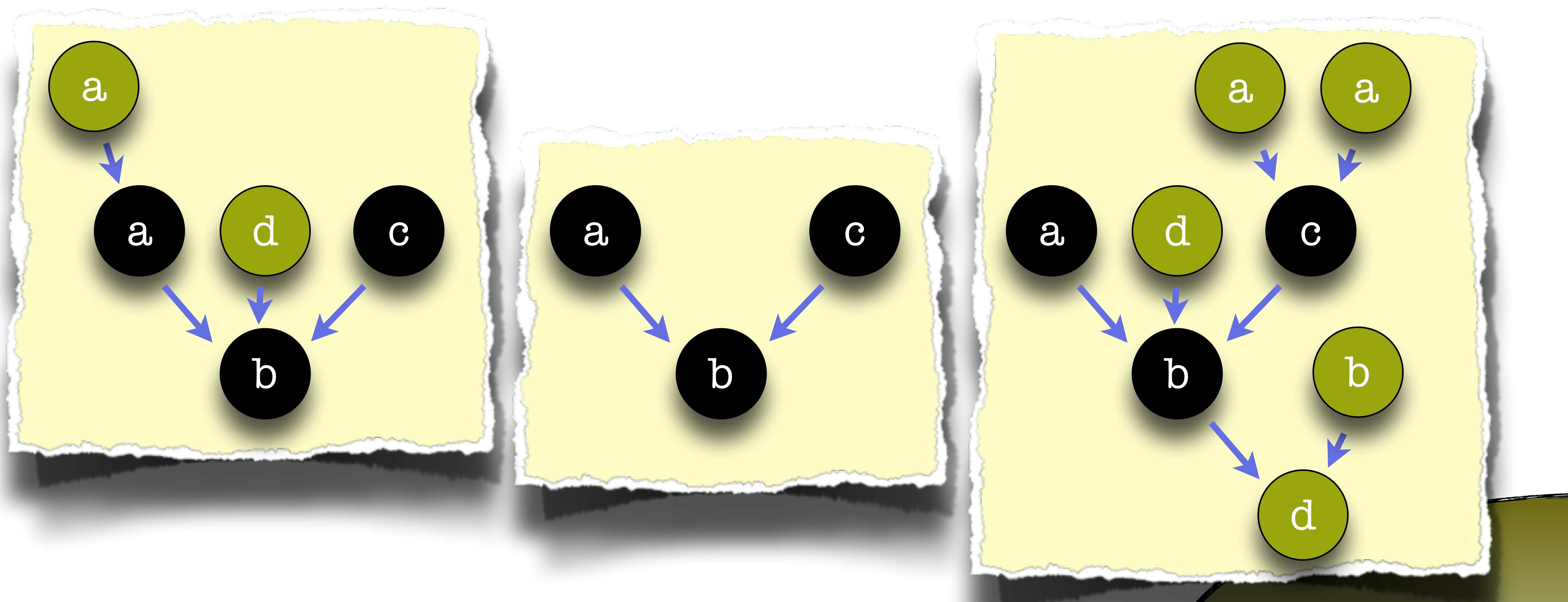
(3)Define an ordering on configurations

Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

(BOUNDED-COVER) DECIDABLE
Theory of Well Structured Transition Systems

(3)Define an ordering on configurations



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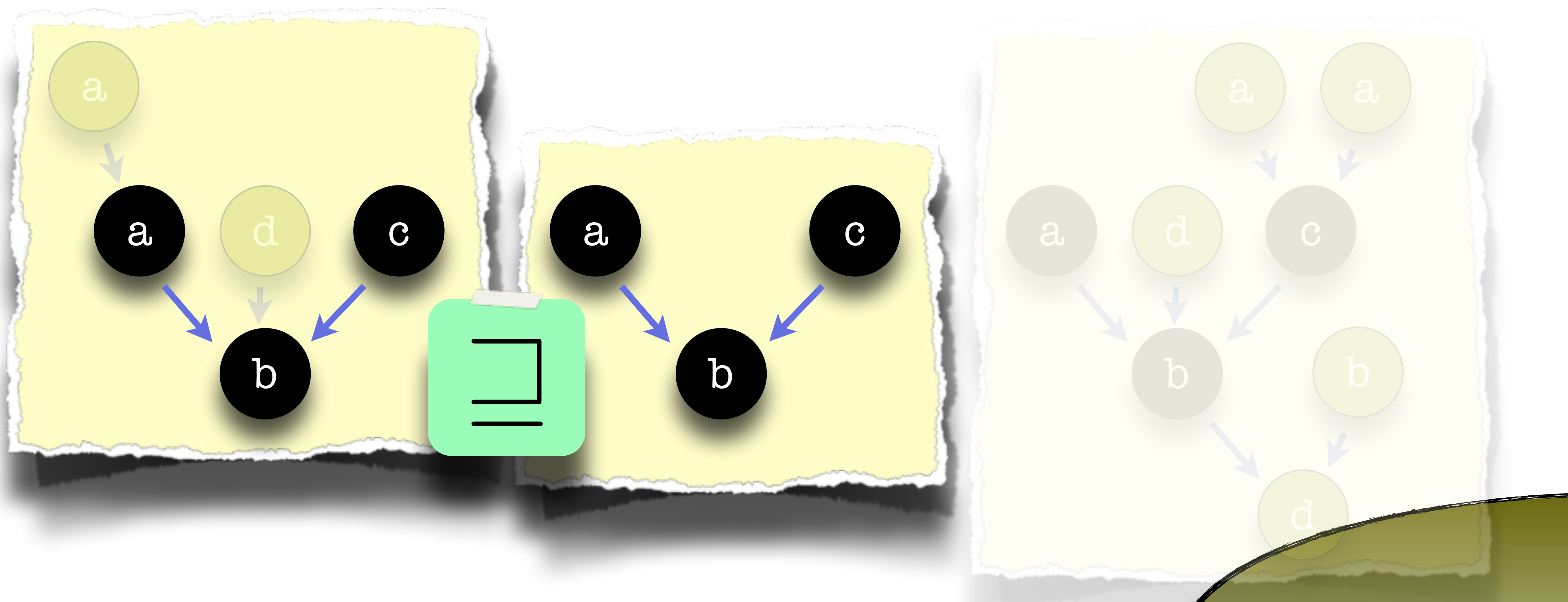

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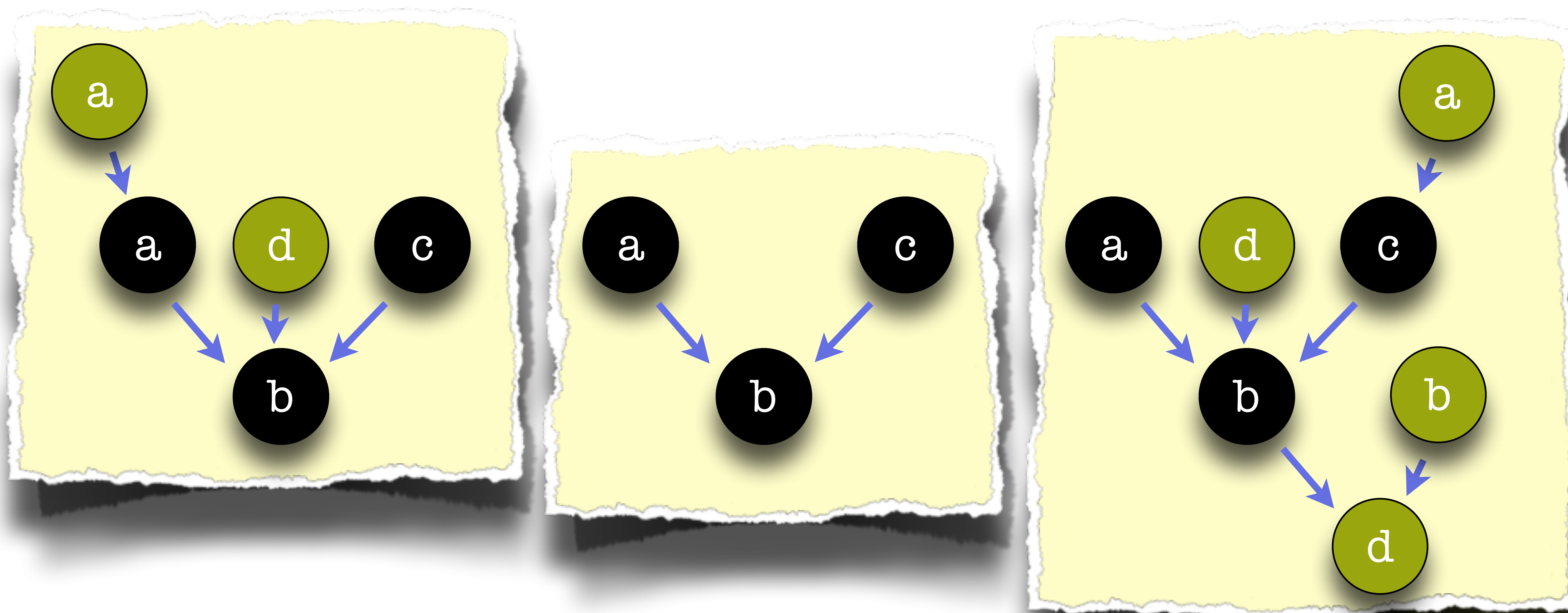
Theory of Well Structured Transition Systems

(3)Define an ordering on configurations



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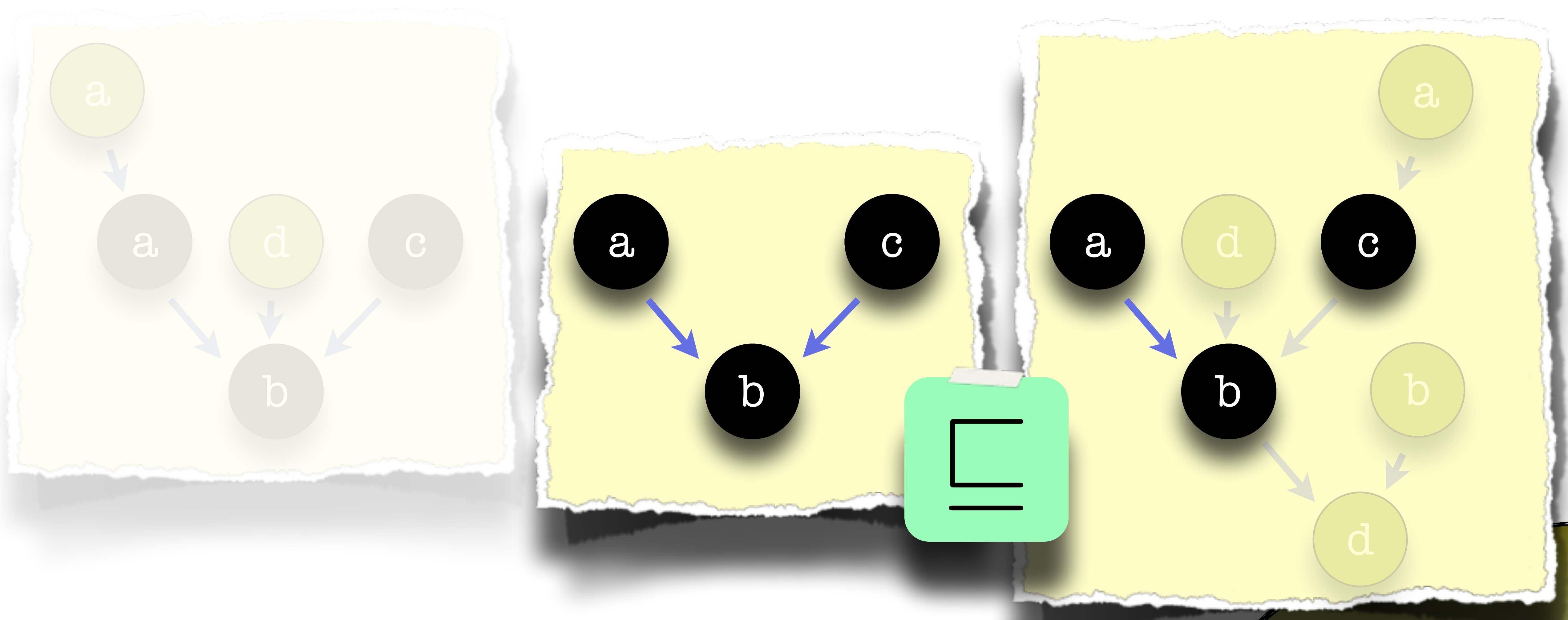

Directed Acyclic

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Theory of Well Structured Transition Systems

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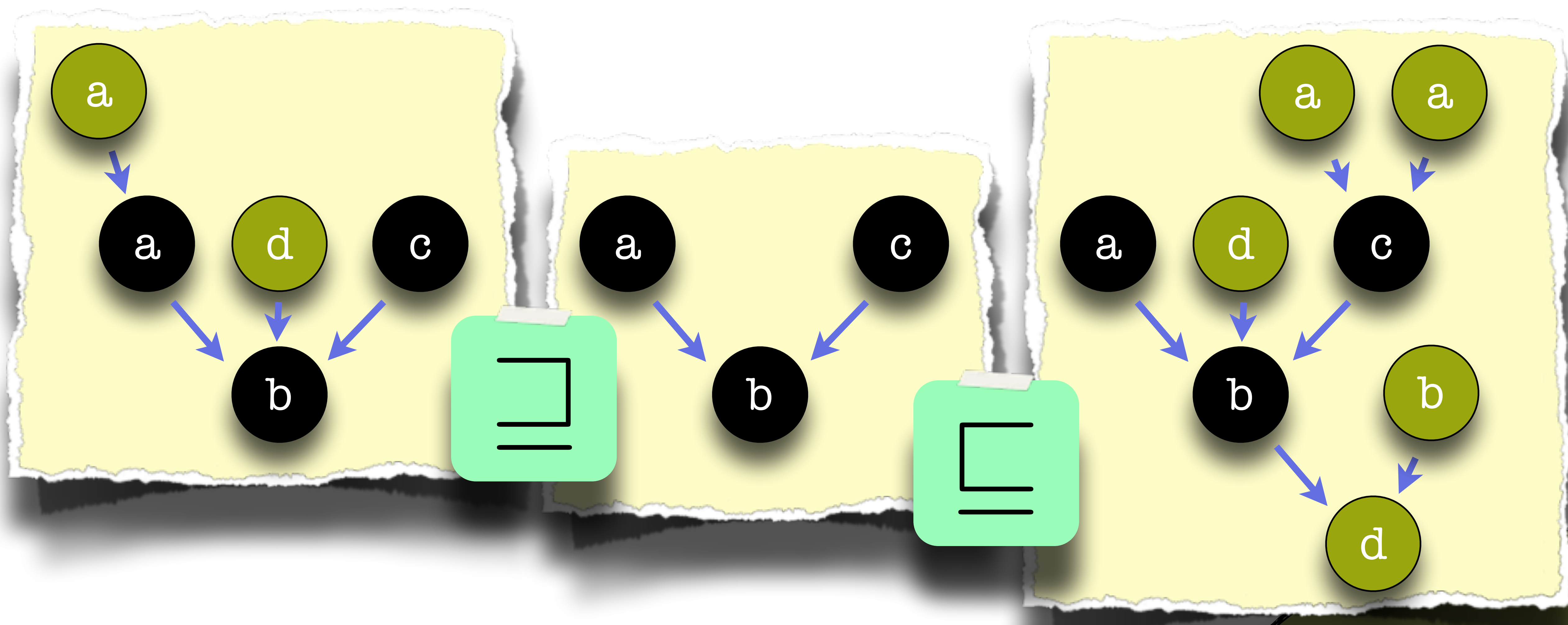
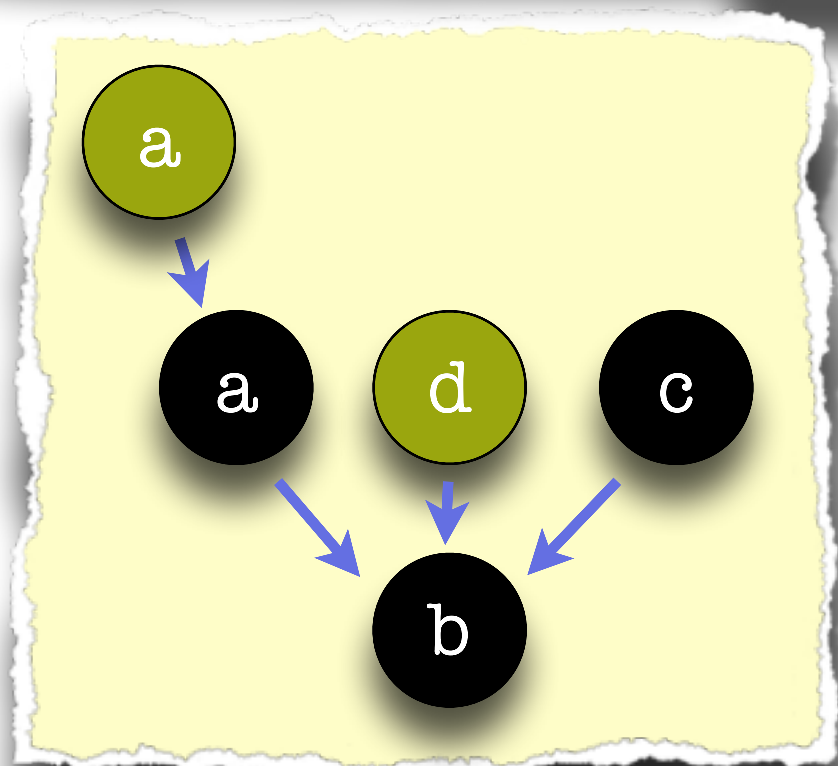


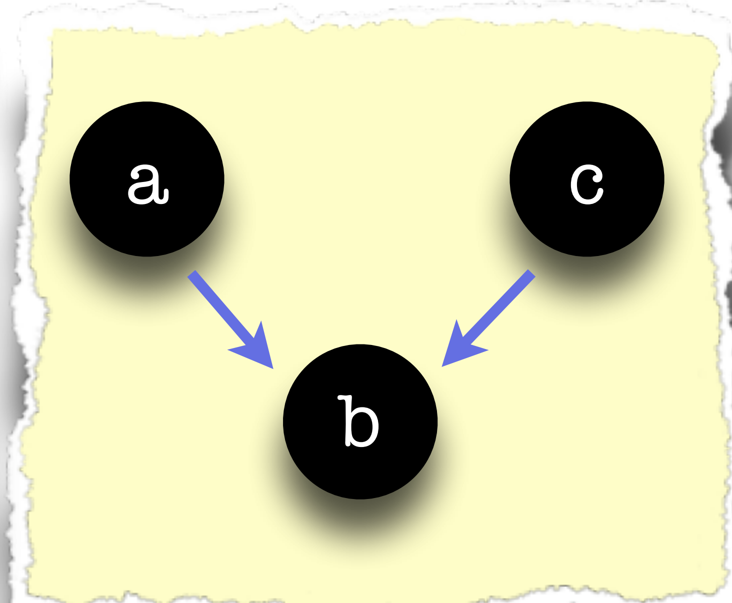
(BOUNDED-COVER) DECIDABLE

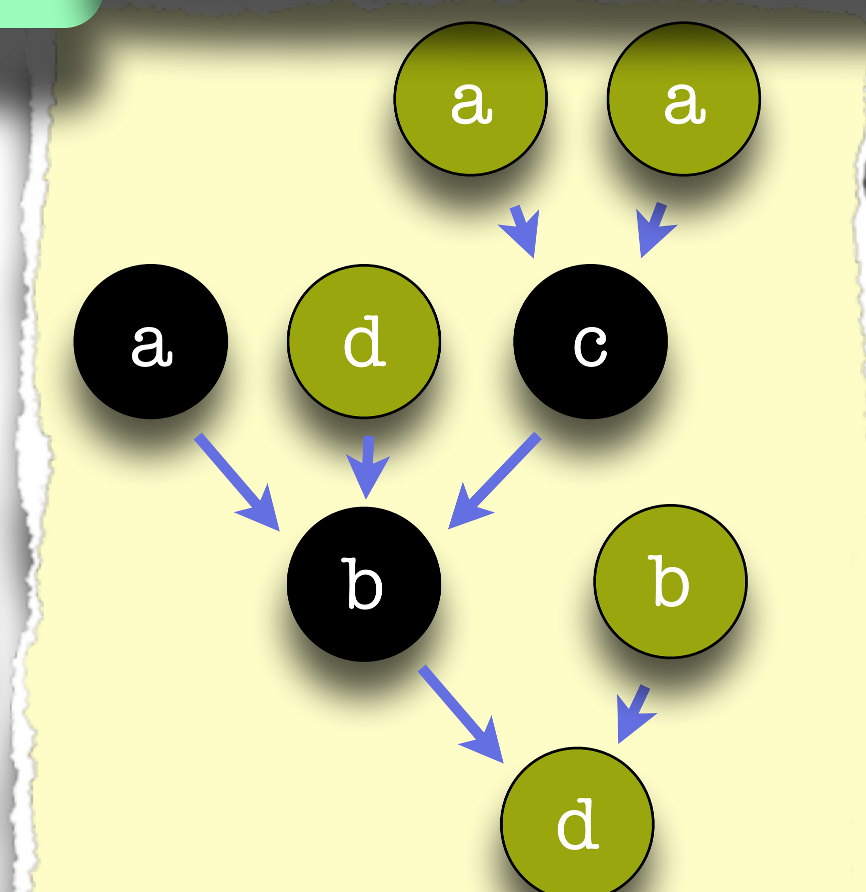
Theory of Well Structured Transition Systems

(3)Define an ordering on configurations

$< b, [a[a], d, c] > \sqsupseteq < b, [a, c] > \sqsubseteq < d, [b[a, d, c[a^2]], b] >$



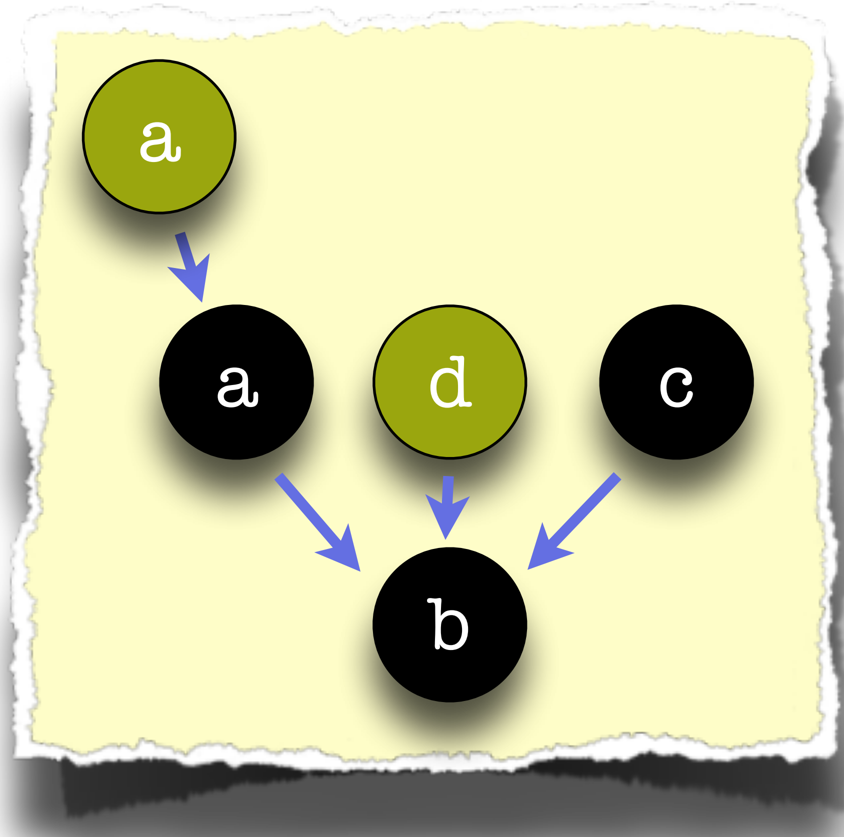


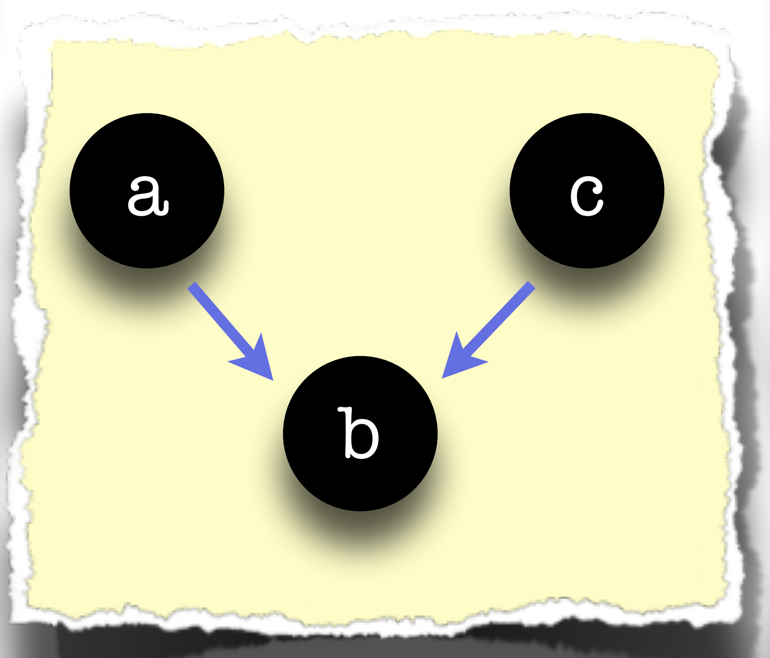


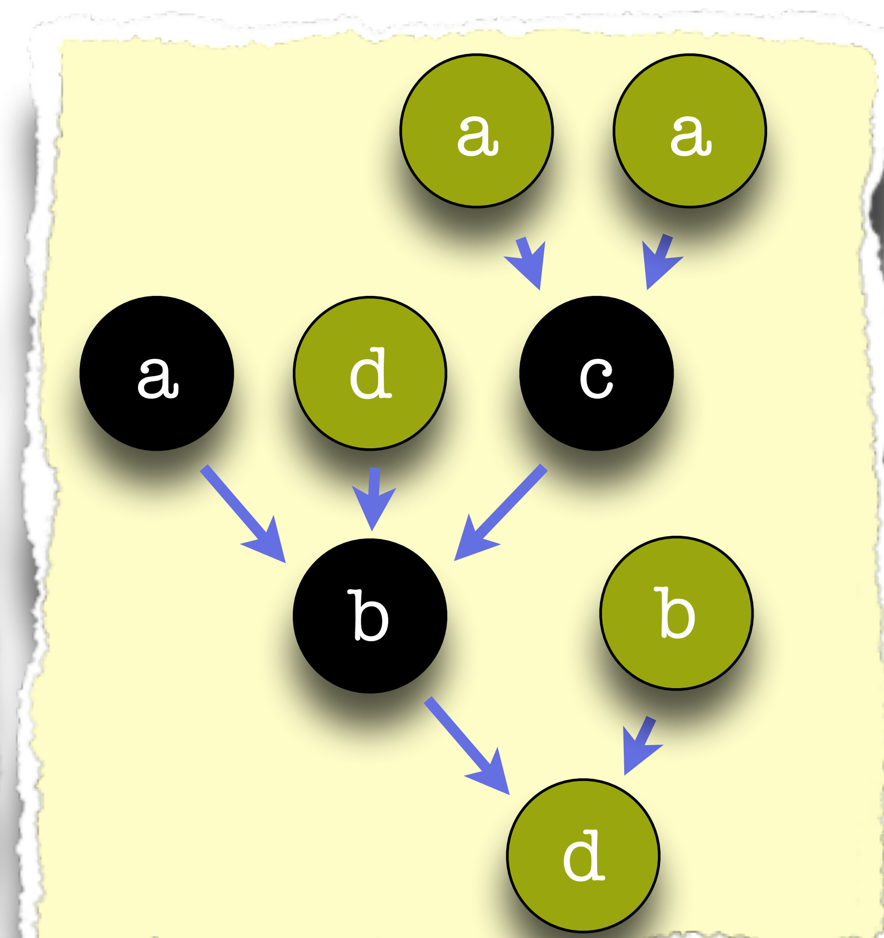
Directed Acyclic

(BOUNDED-COVER) DECIDABLE
Theory of Well Structured Transition Systems

(3)Define an ordering on configurations







Directed Acyclic

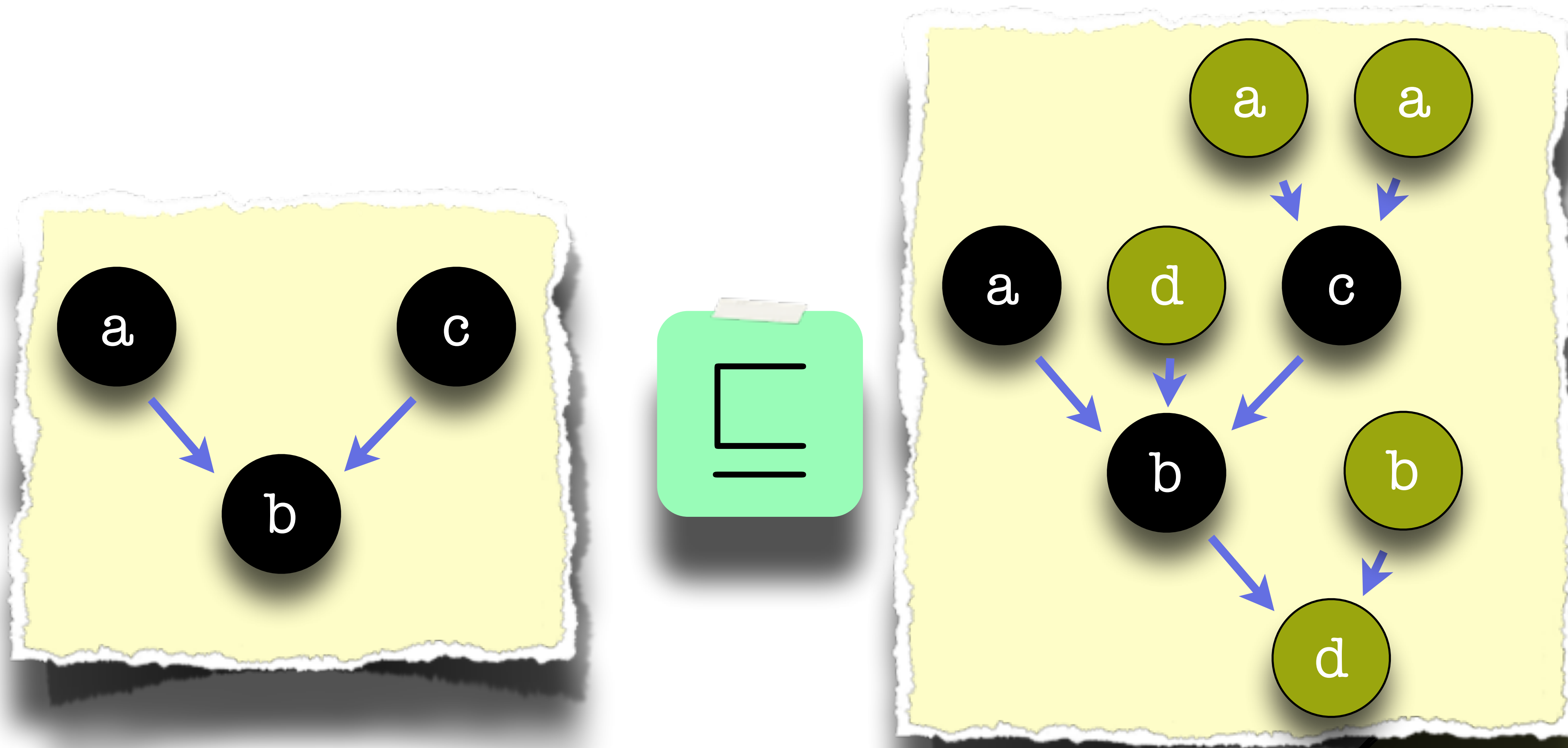
- Motivation
- Reachability
- Bounded Depth Reachability

Monotonicity

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(3)Define an ordering on configurations



Directed Acyclic

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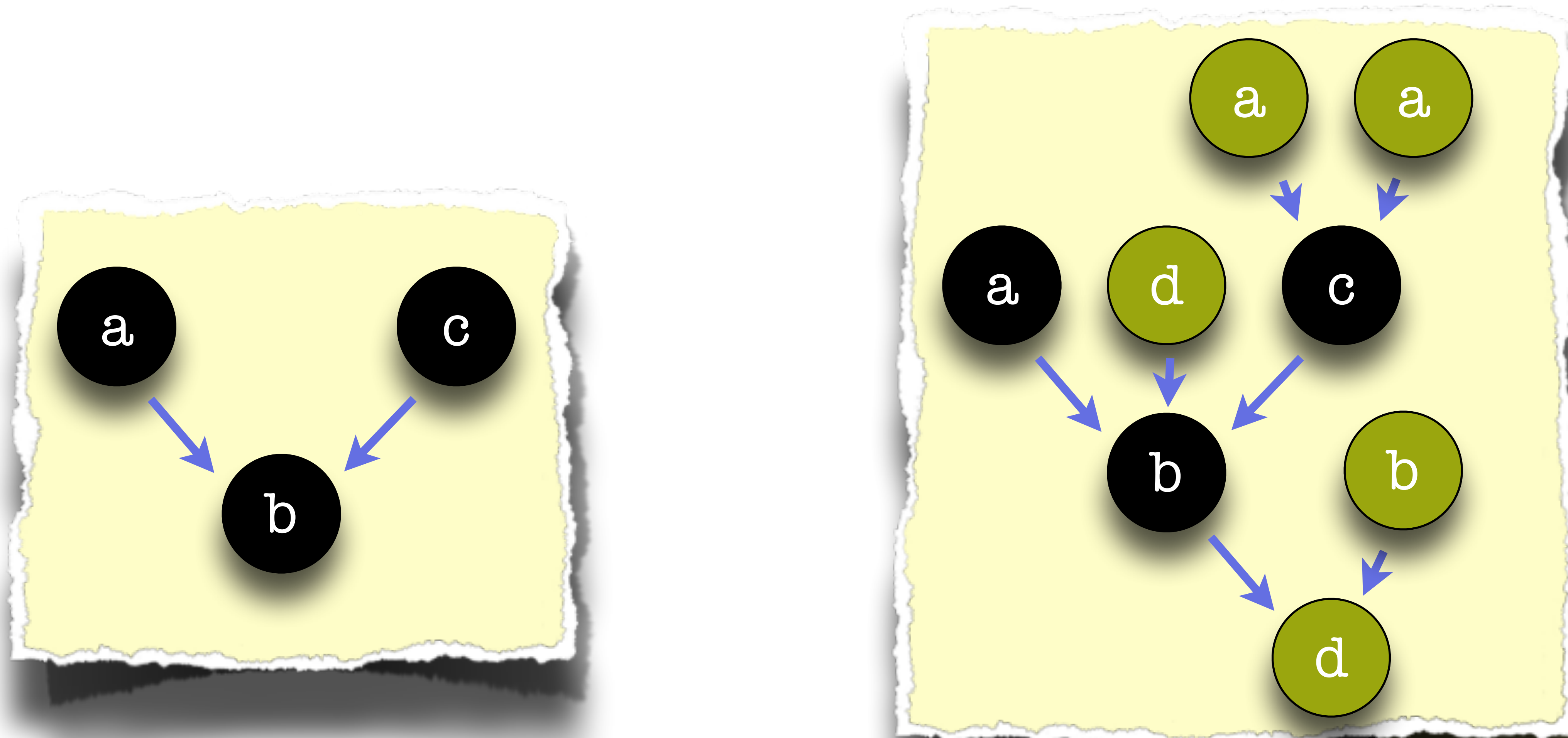

Directed Acyclic

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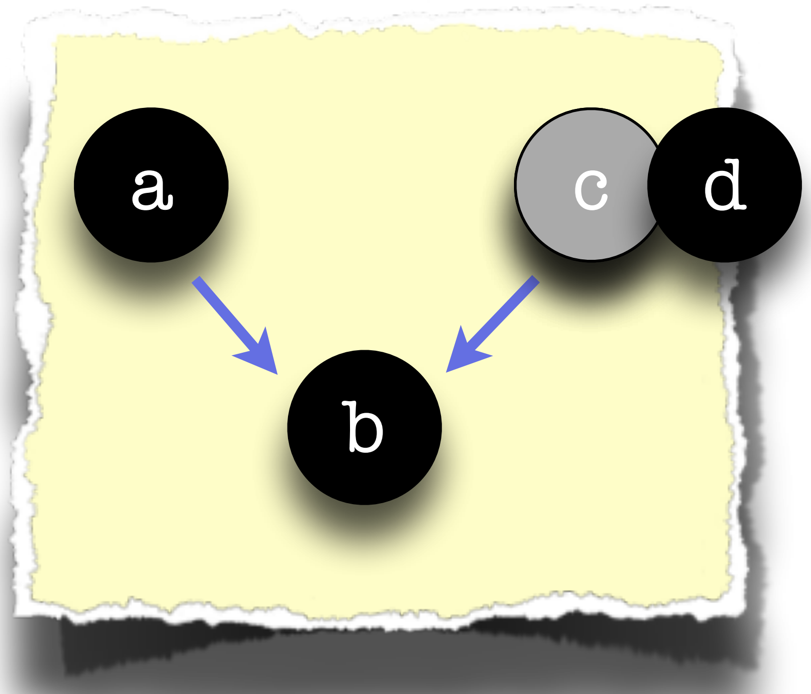
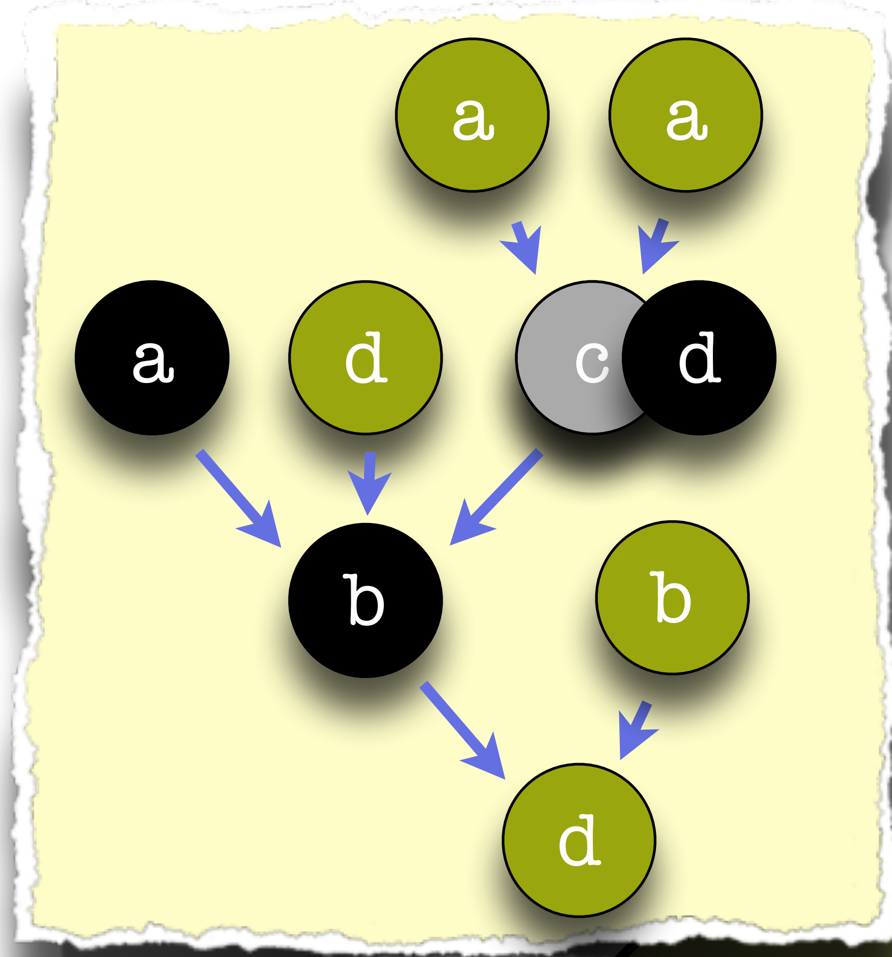
Monotonicity
(BOUNDED-COVER) DECIDABLE
Theory of Well Structured Transition Systems

(3)Define an ordering on configurations

- Broadcast: c -> d





Directed Acyclic

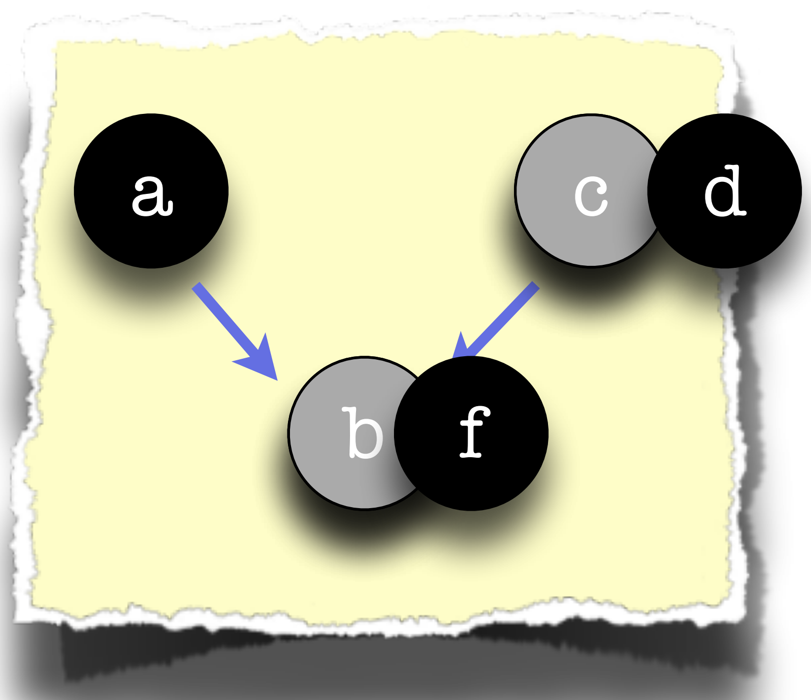
Monotonicity

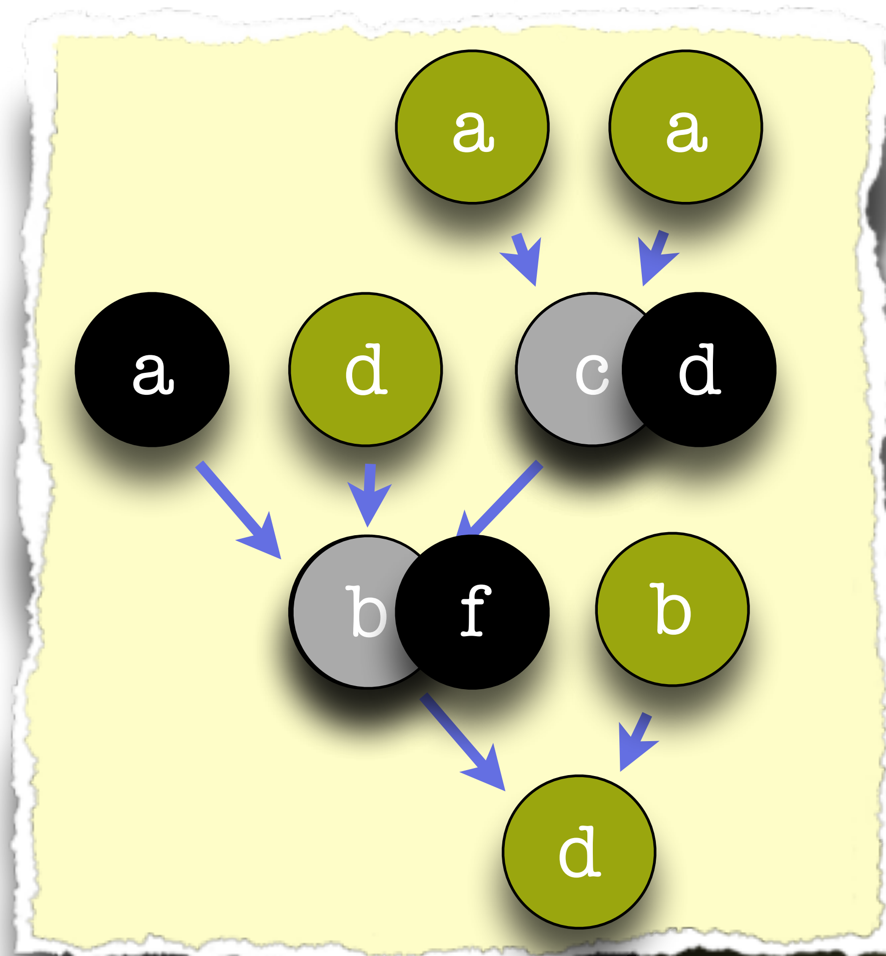
(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(3)Define an ordering on configurations

- Broadcast: c -> d
- Receive: b -> f





Directed Acyclic

Monotonicity

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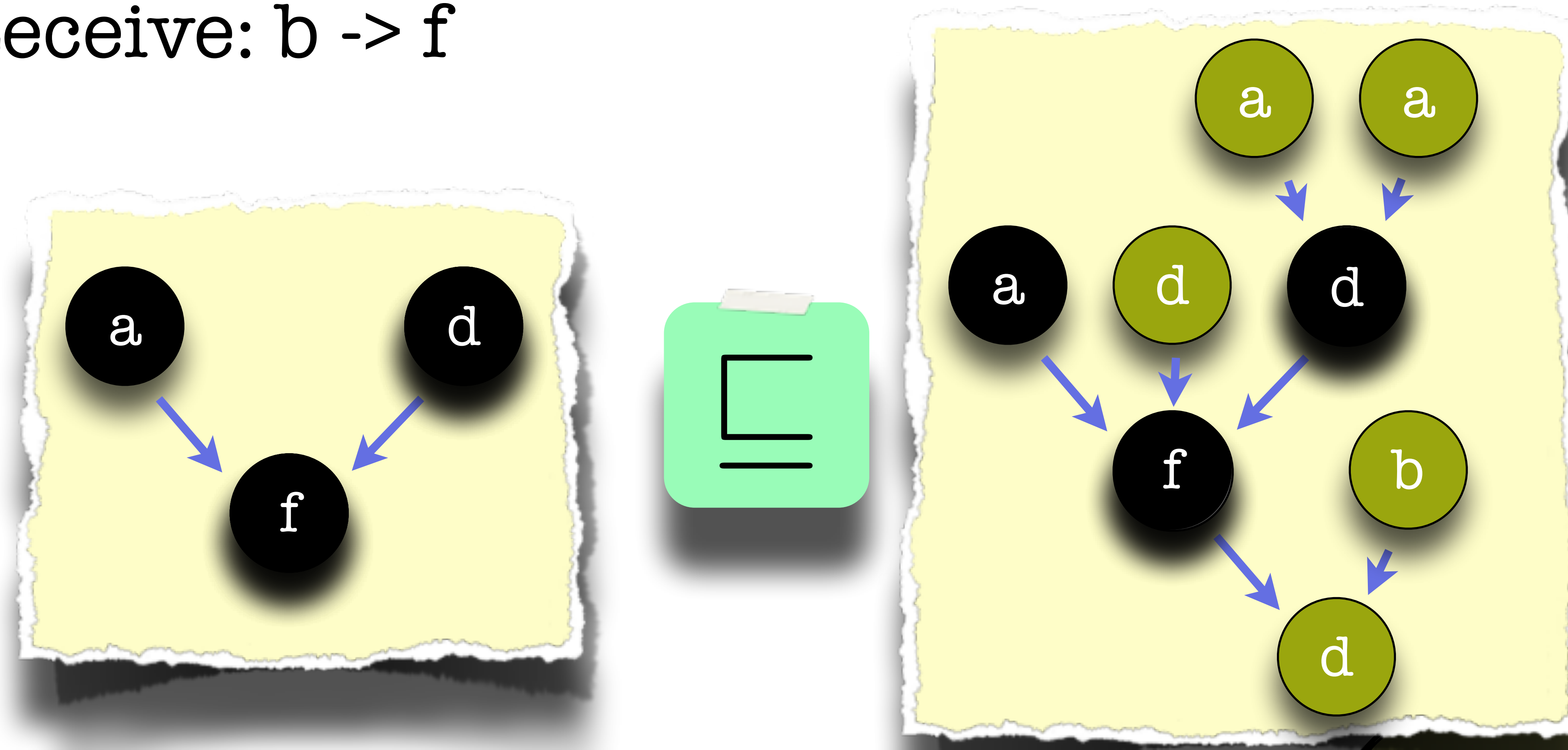

Directed Acyclic

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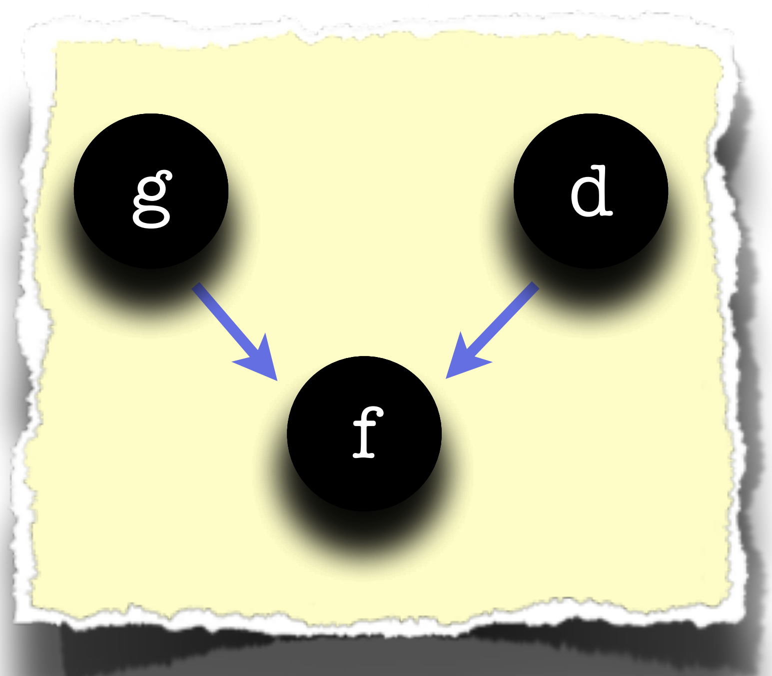
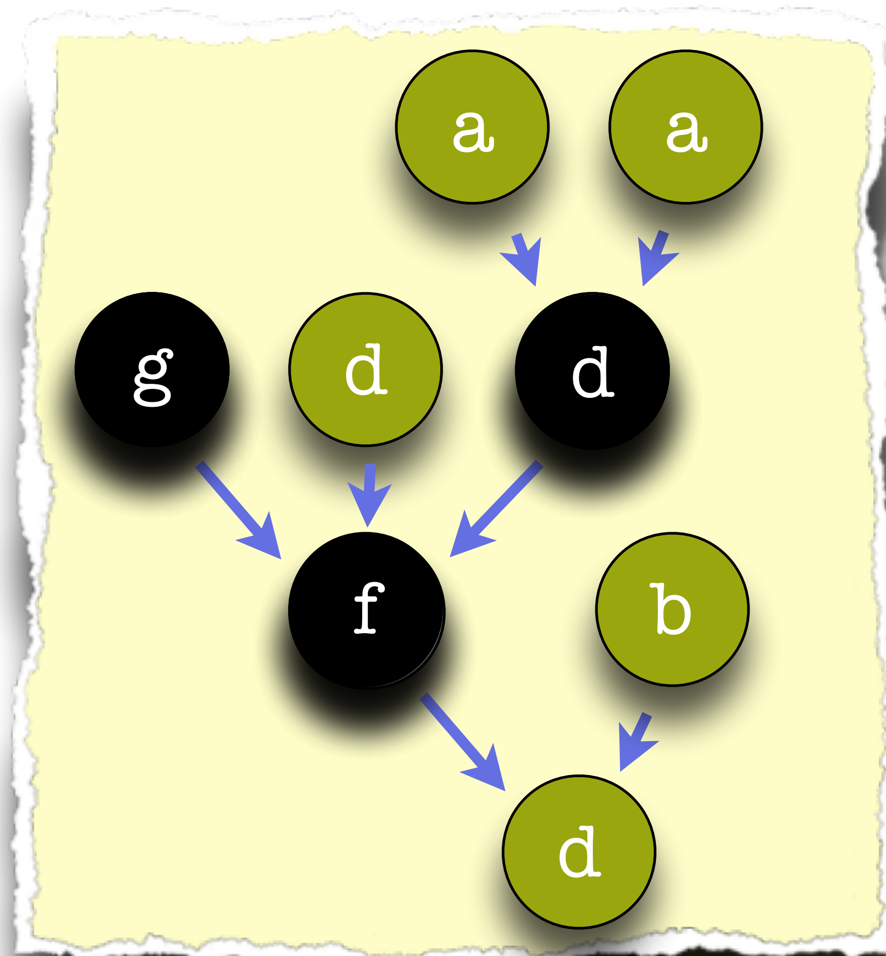
Monotonicity
(BOUNDED-COVER) DECIDABLE
Theory of Well Structured Transition Systems

(3)Define an ordering on configurations

- Broadcast: c -> d
- Receive: b -> f
- Local: a -> g





Directed Acyclic

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Monotonicity

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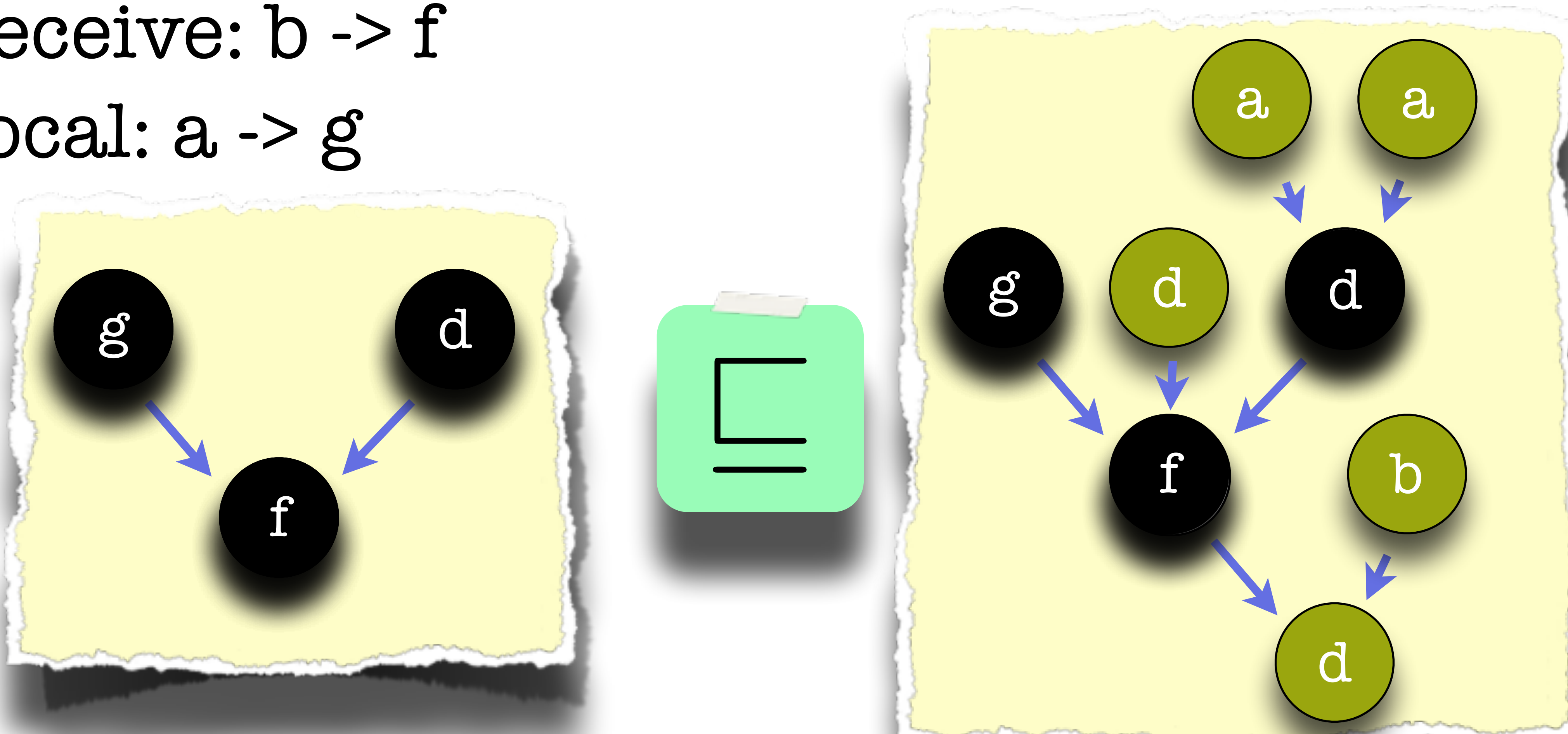

Ad-Hoc Networks

- Model
- Transition System
- Reachability

Directed Acyclic

- Motivation
- Reachability
- Bounded Depth Reachability

FUTURE WORK

- Consider:
  - REPEATED-COVER
  - Bounded number of Phases
- Dynamic Communicating Automata

S·ACADEMIAE UBSALIENSIS

GRATIAE

VERITAS

NATURAE

Directed Acyclic

- TRANSD proof

Directed Acyclic

- TRANSD proof

Control State Reachability (COVER)

Undecidable

Cover is Undecidable

Sketch of the proof:

- TRANSD Problem
- TRANSD Undecidable
- Encode TRANSD into COVER

Directed Acyclic

- TRANSD proof

Undecidable

Sketch of the proof:

- TRANSD Problem
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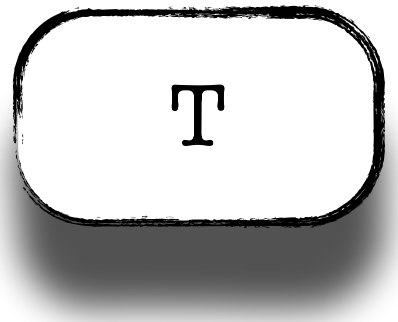

Directed Acyclic

- TRANSD proof

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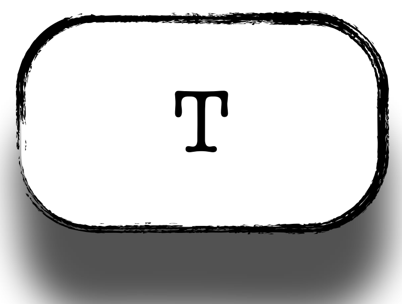

Directed Acyclic

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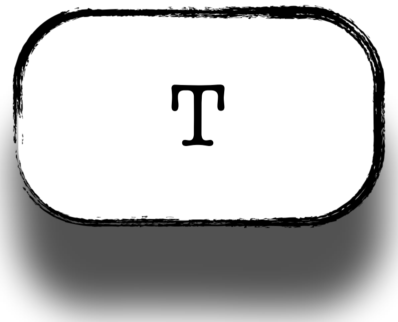

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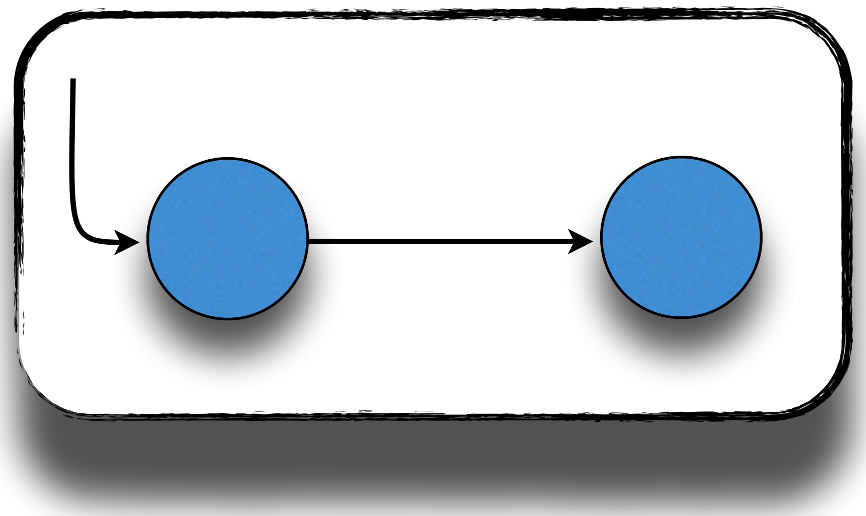

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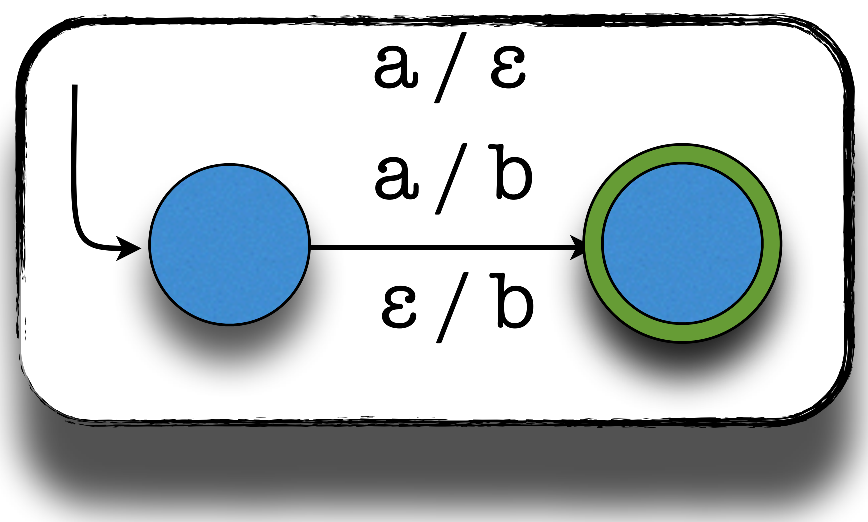

Input / Output Language

Directed Acyclic

Undecidable

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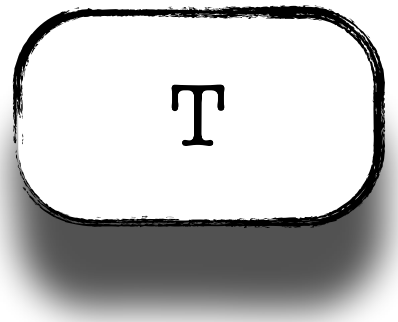

Directed Acyclic

▸ TRANSD proof

Undecidable

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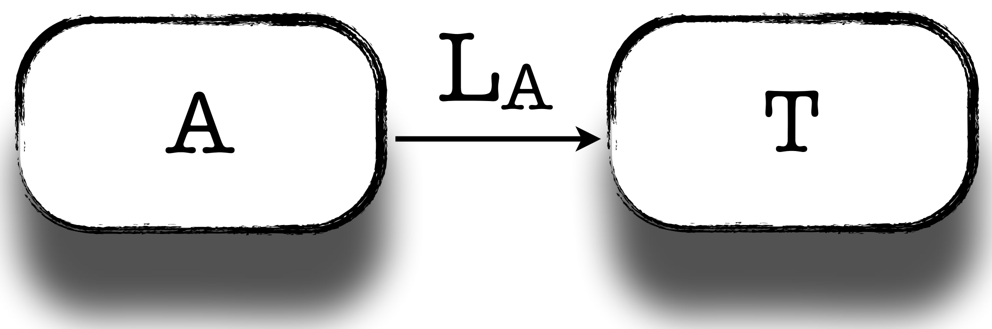

Directed Acyclic

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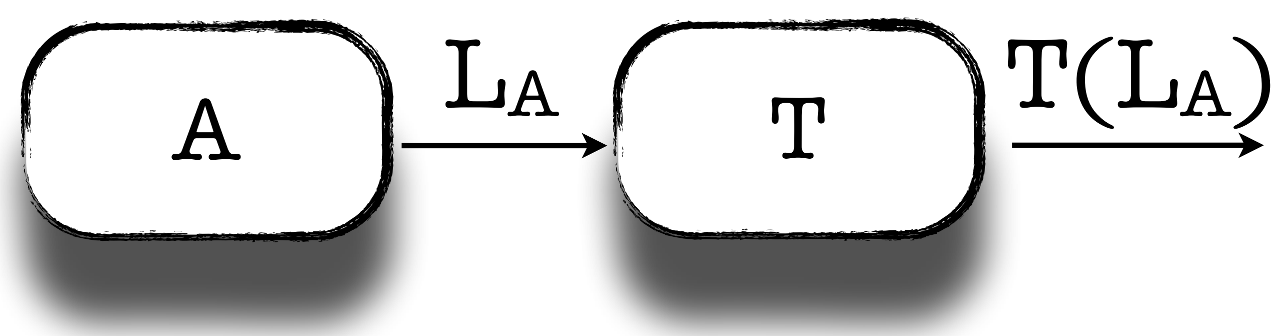

Directed Acyclic

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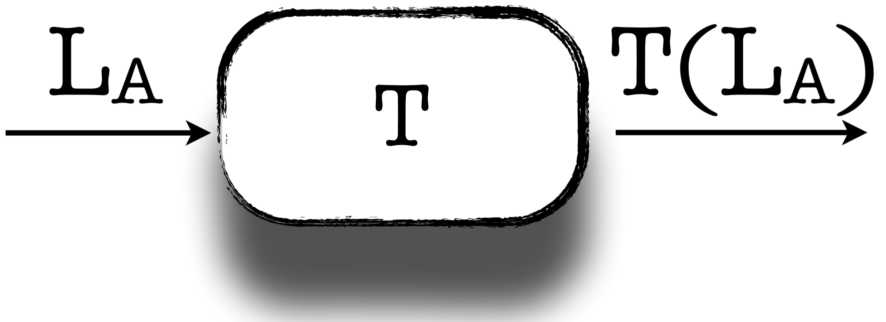

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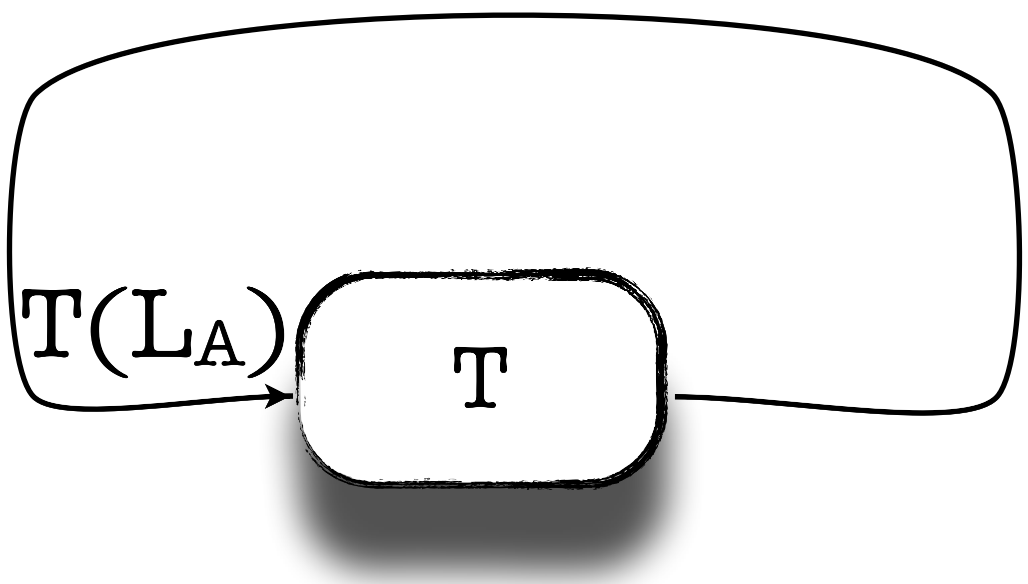

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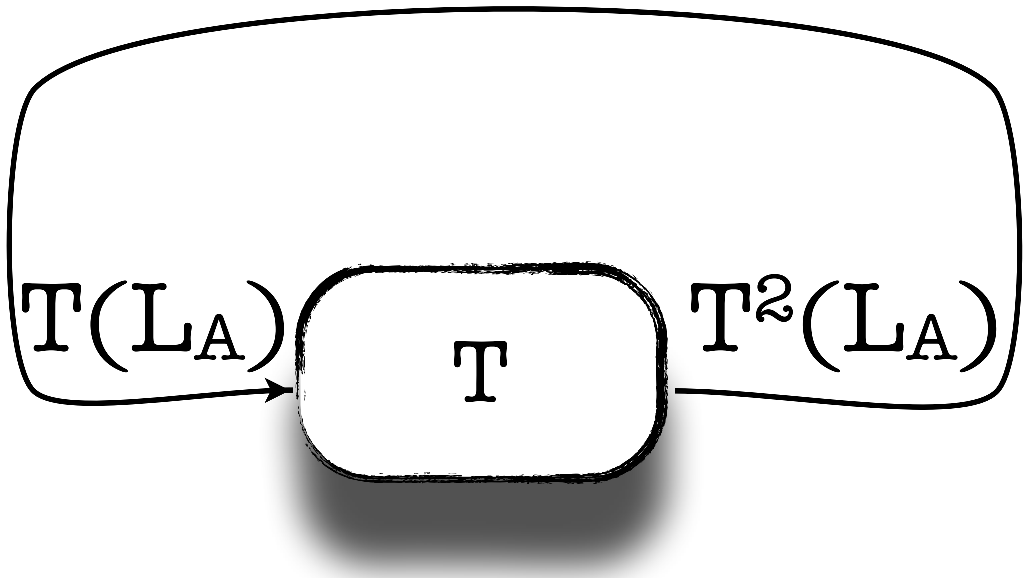


Directed Acyclic

Undecidable

Sketch of the proof:

- TRANSD Problem
- TRANSD Undecidable
- Encode TRANSD into COVER

$T^2(L_A)$

Undecidable

Sketch of the proof:

- TRANSD Problem
- TRANSD Undecidable
- Encode TRANSD into COVER

$T^k(L_A)$

Directed Acyclic

▸ TRANSD proof

Undecidable

Sketch of the proof:

- TRANSD Problem
- TRANSD Undecidable
- Encode TRANSD into COVER

$T^k(L_A)$

Undecidable

Sketch of the proof:

- TRANSD Problem
- TRANSD Undecidable
- Encode TRANSD into COVER

Given A, B and T, is there k

$T^k(L_A)$

Directed Acyclic

Undecidable

Sketch of the proof:

- TRANSD Problem
- TRANSD Undecidable
- Encode TRANSD into COVER

Given A, B and T, is there k

$$T^k(L_A) \cap L_B \neq \emptyset$$

Undecidable

Sketch of the proof:

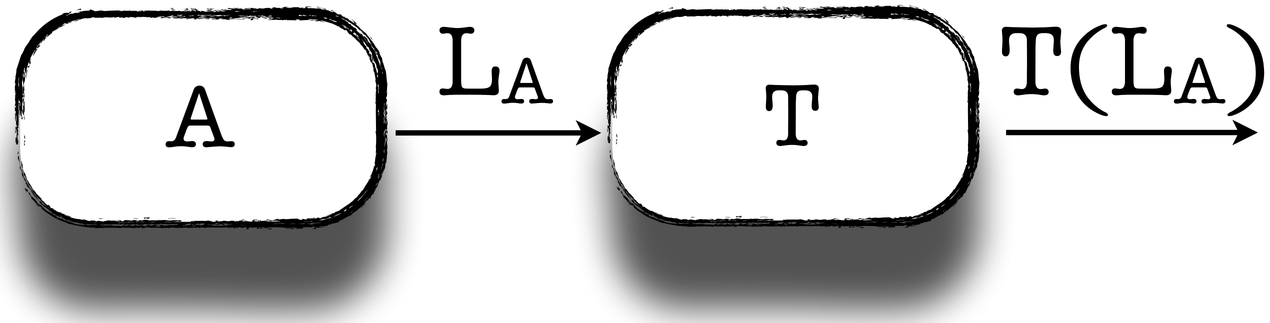
- TRANSD Problem
- TRANSD Undecidable
- Encode TRANSD into COVER

Directed Acyclic

Undecidable

Sketch of the proof:

- TRANSD Problem
- TRANSD Undecidable
- Encode TRANSD into COVER



Directed Acyclic

Undecidable

Sketch of the proof:

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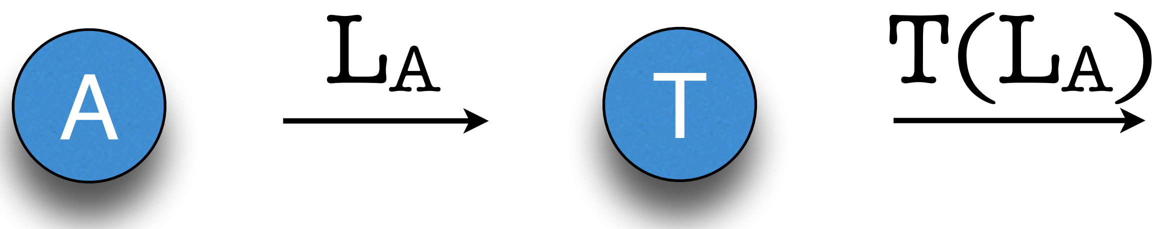

Directed Acyclic

Undecidable

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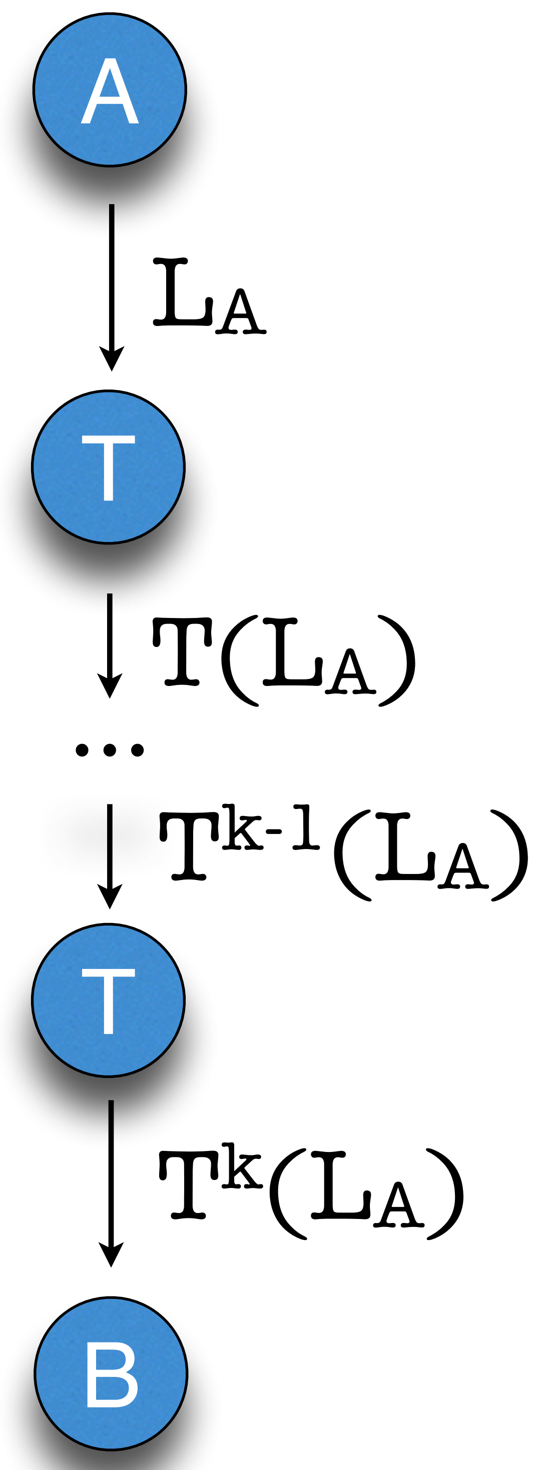
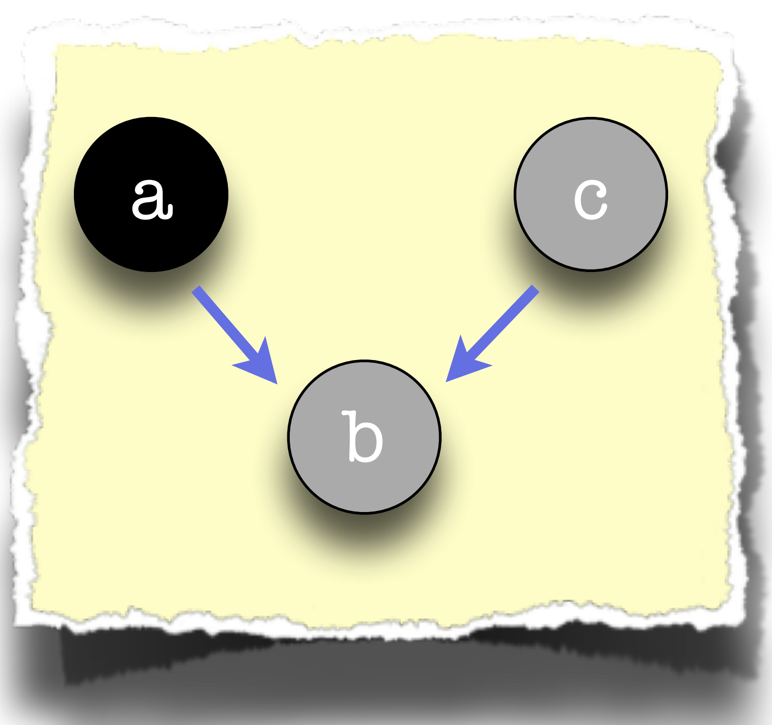
‣ TRANSD proof

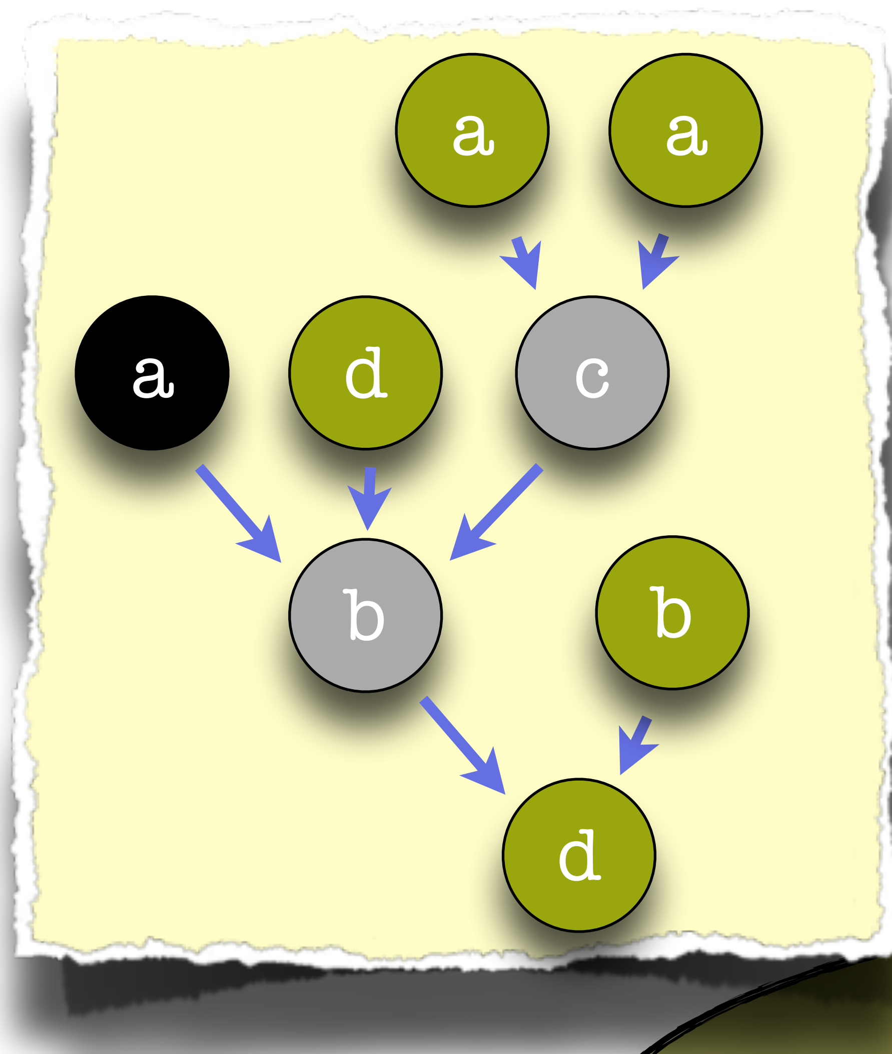


Directed Acyclic

Monotonicity

Process transitions:

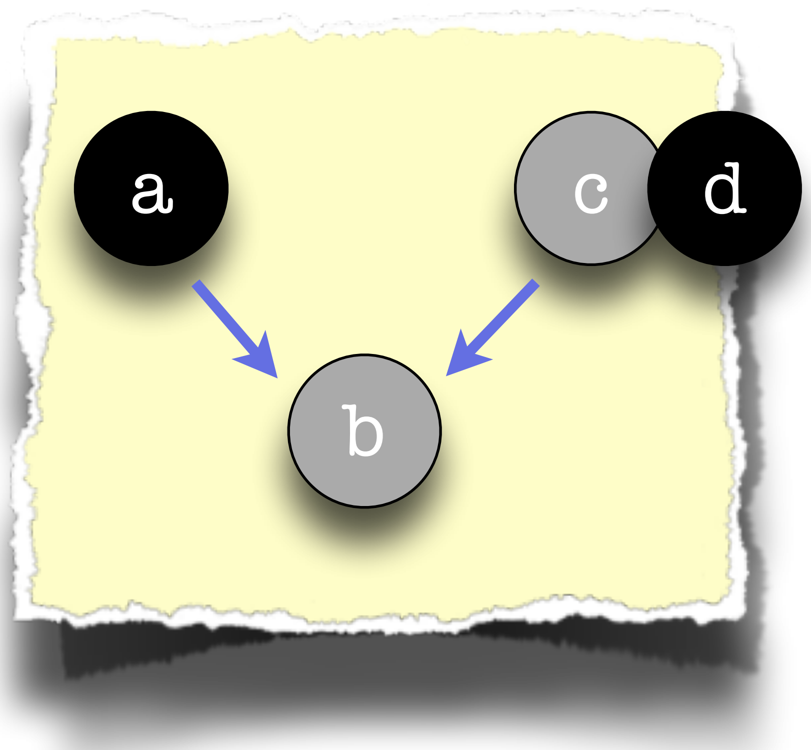


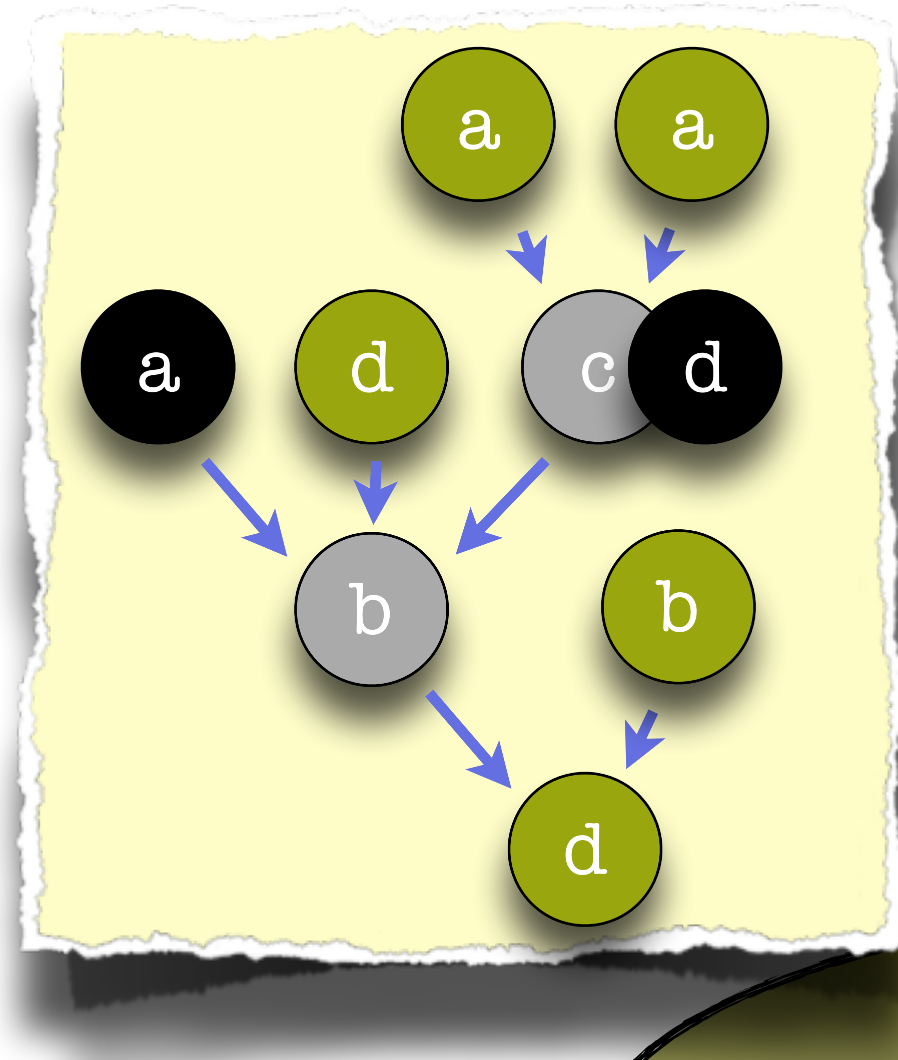


Monotonicity

Process transitions:

- Broadcast: c -> d





Monotonicity

Process transitions:

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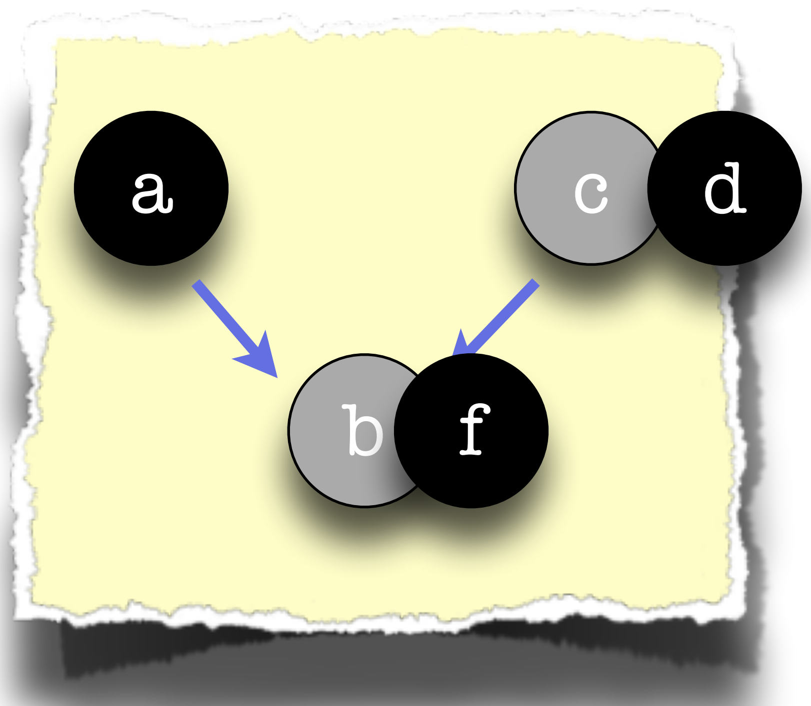
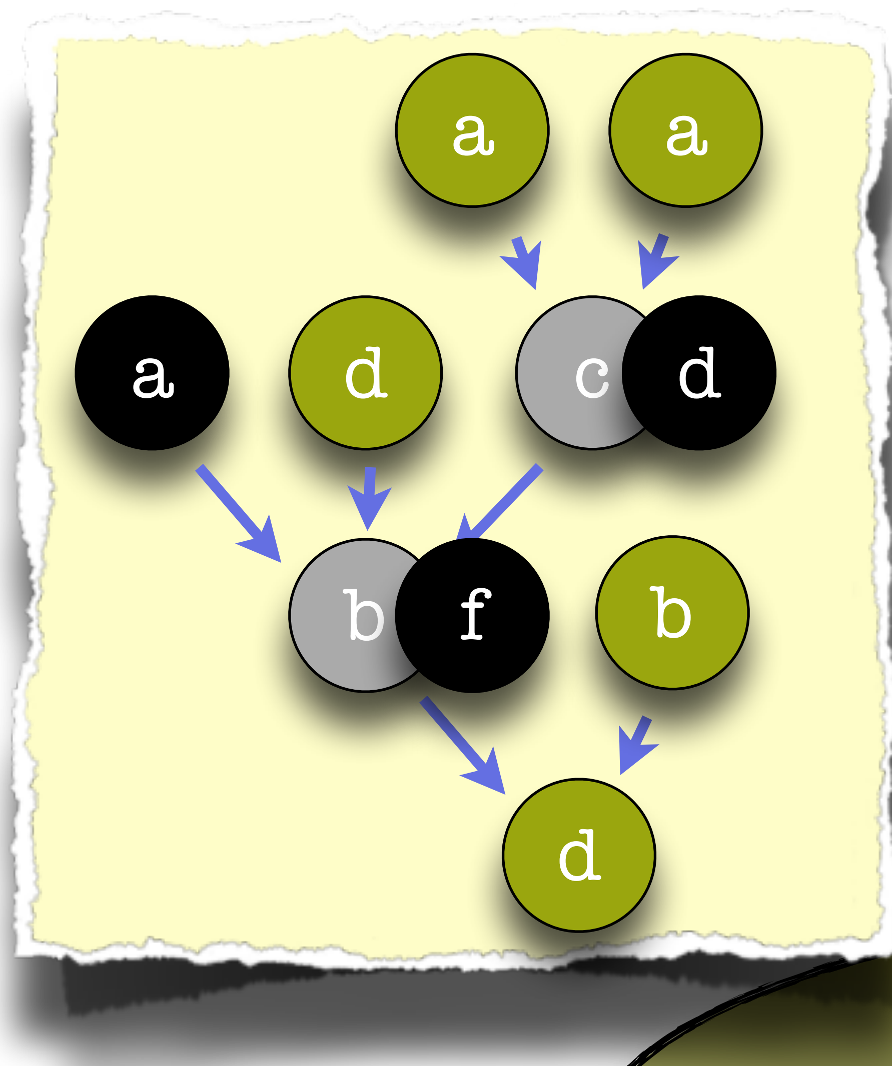
- Receive: b -> f





Directed Acyclic

- Motivation
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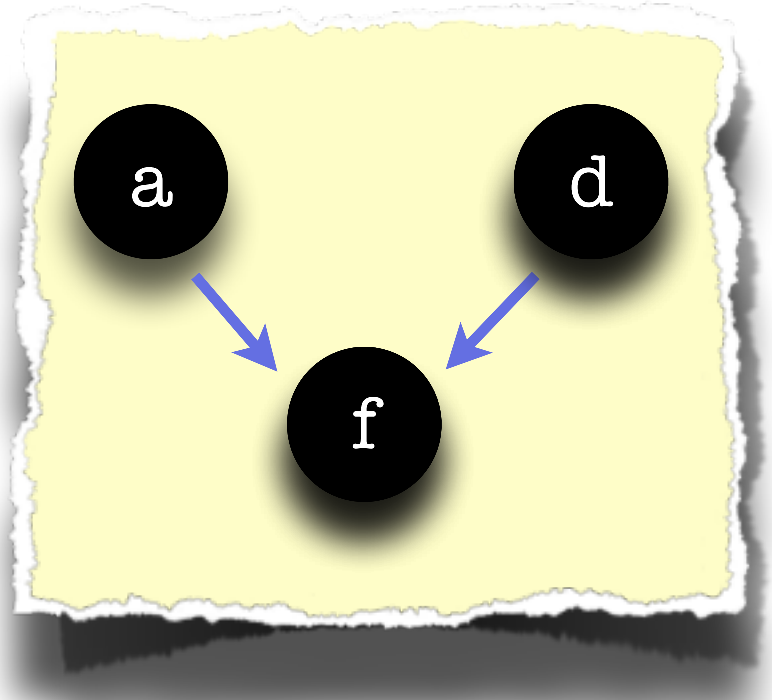

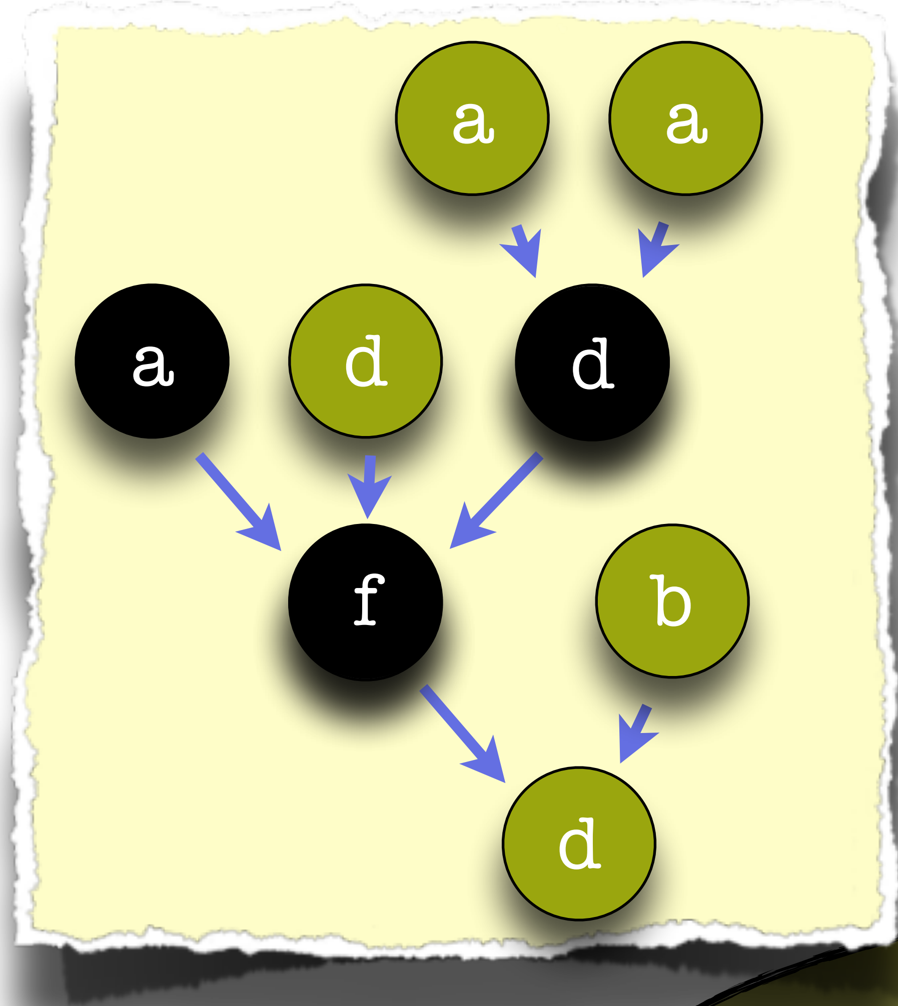

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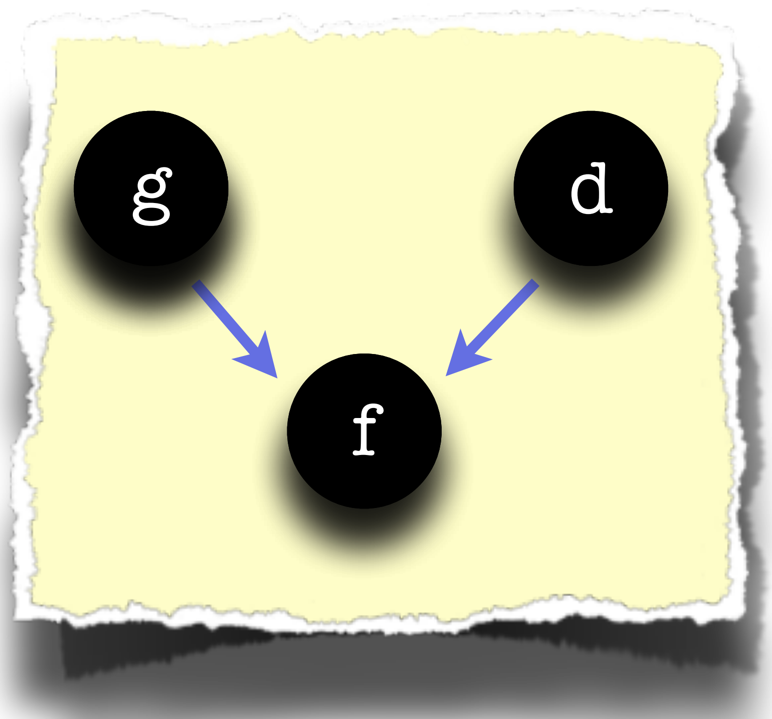

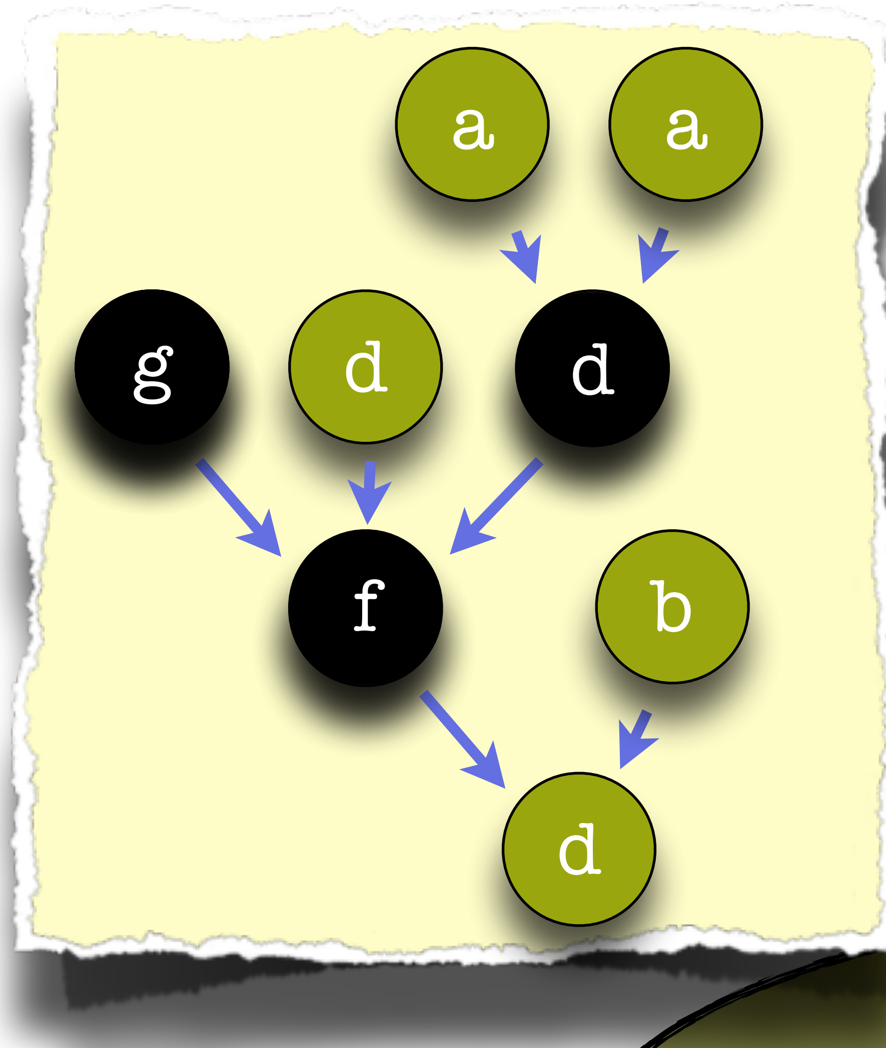

(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

(3)Use the WSTS framework

- Γ : Inverted Tree Configurations $\gamma | height(\gamma) = q_0$

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- U : Upward closed set; minimal element $\{q\}$

Directed Acyclic

- Definition
- Motivation
- COVER
- BOUNDED-COVER

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(BOUNDED-COVER) DECIDABLE

Theory of Well Structured Transition Systems

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Reachability is decidable if, for any $\gamma \in \Gamma$

- We can check if $\gamma \in \Gamma_{init}$
- We can compute the minimal set of $Pre(\gamma)$, and it's finite

S·ACADEMIAE UBSALIENSIS

GRATIAE

VERITAS

NATURAE