Ensuring Liveness Properties of Distributed Systems with Justness

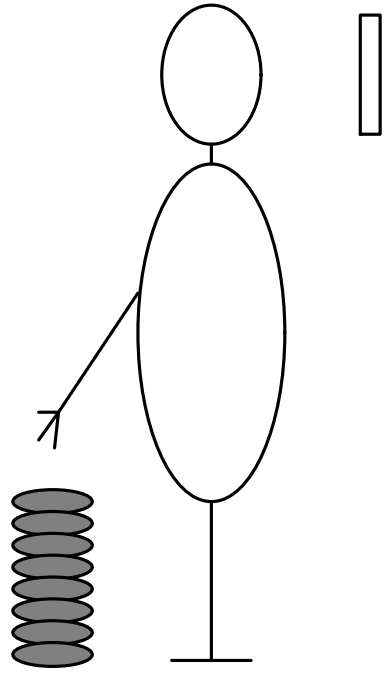
Rob van Glabbeek

University of Edinburgh

June 2023

Liveness properties – an example

Something good will eventually happen.



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Liveness property: at least 3 quarters will be inserted.

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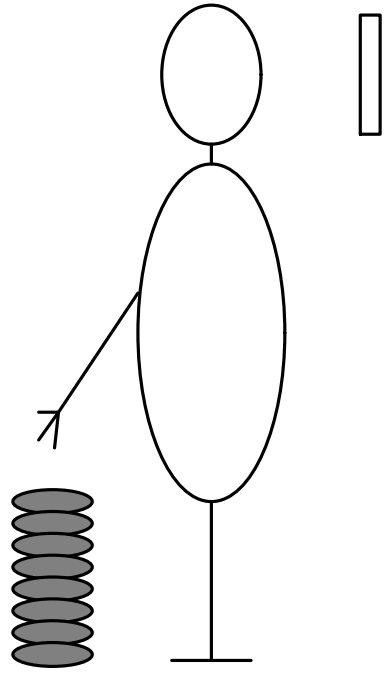

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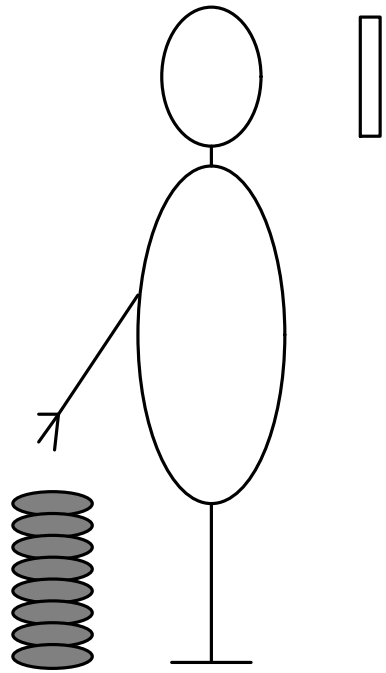

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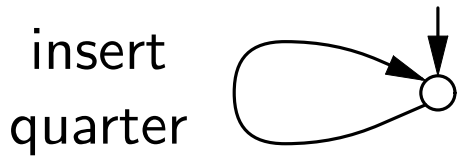
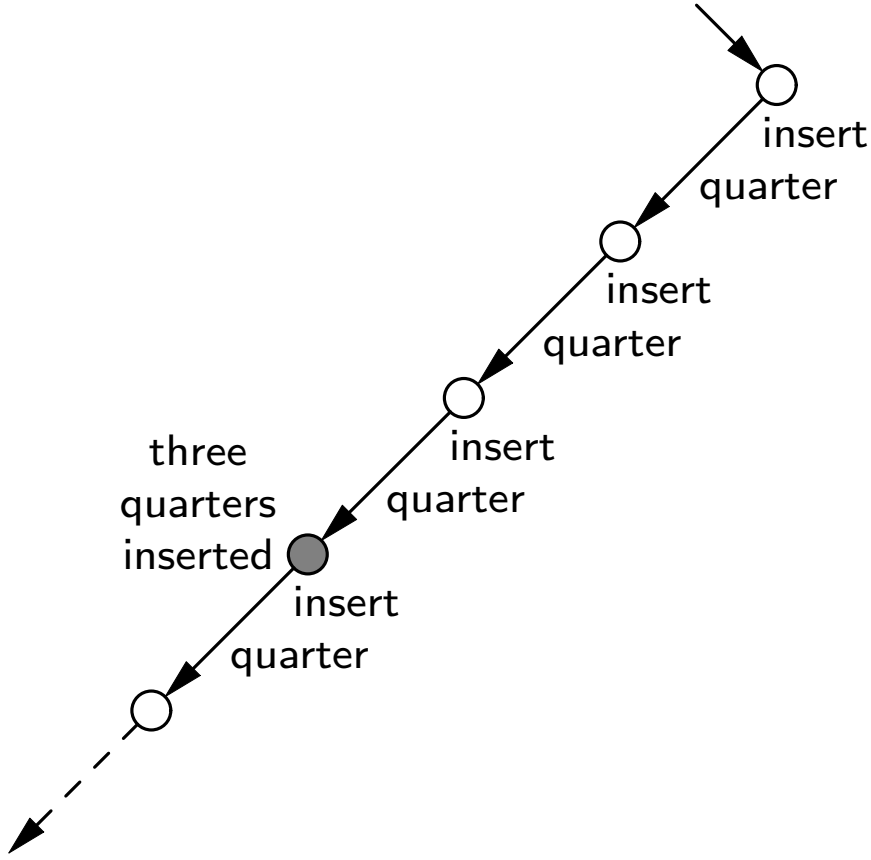
The assumption that a system will not stop without a reason.

Transition system of example



Transition system with success state



Progress, Justness, Fairness and Liveness

Fairness

$\Downarrow$

Justness

$\Downarrow$

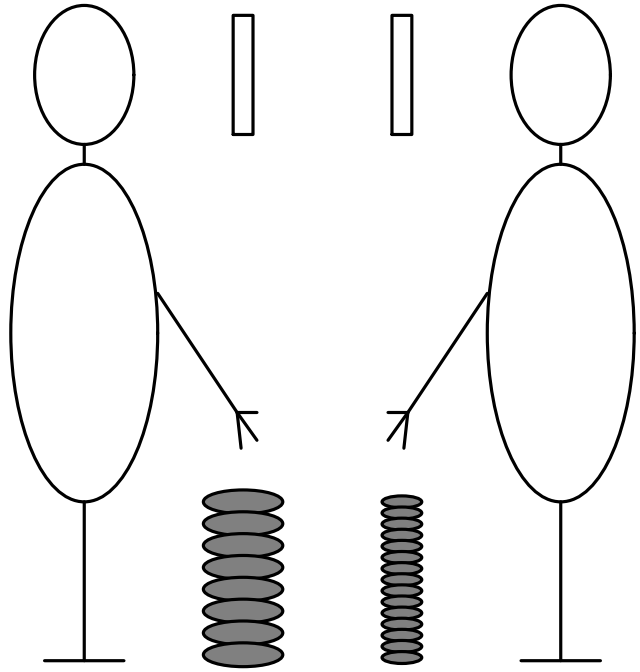
Progress

a hierarchy of assumptions

Liveness properties

somethings one want to obtain,
optionally
when making one such assumption

Liveness properties – a more interesting example



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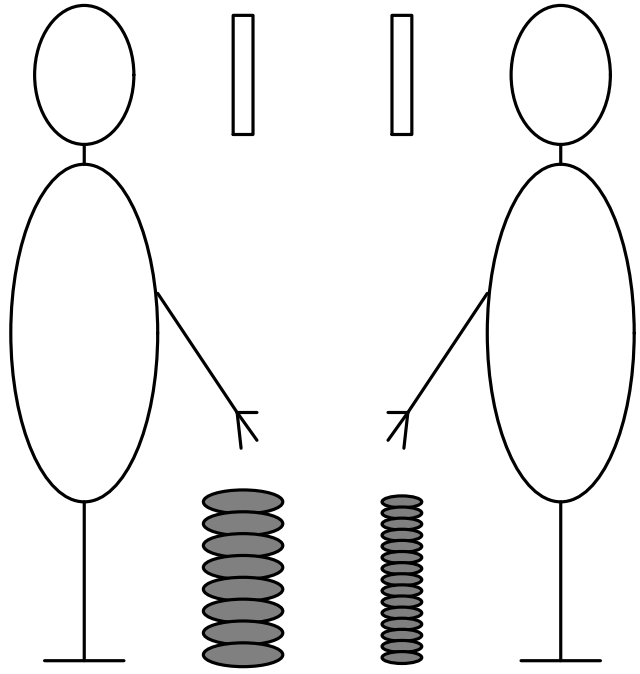

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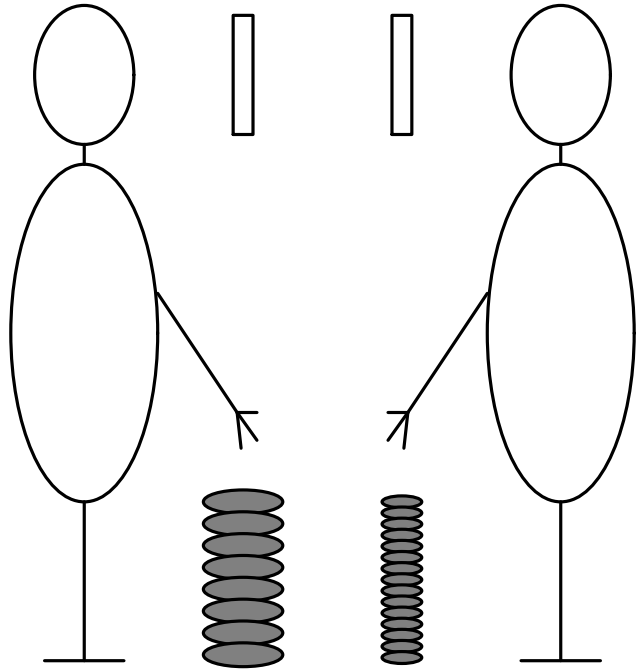

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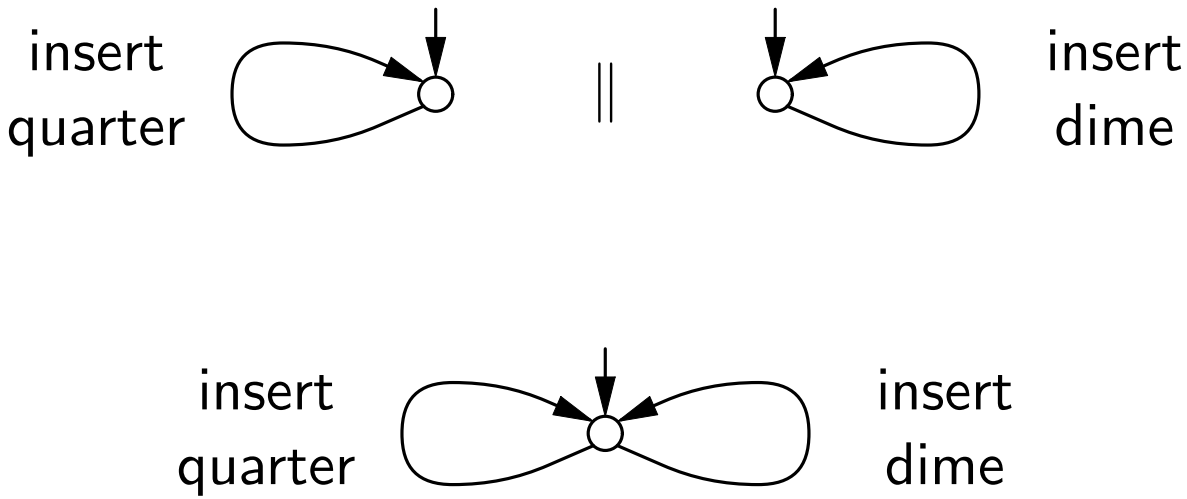

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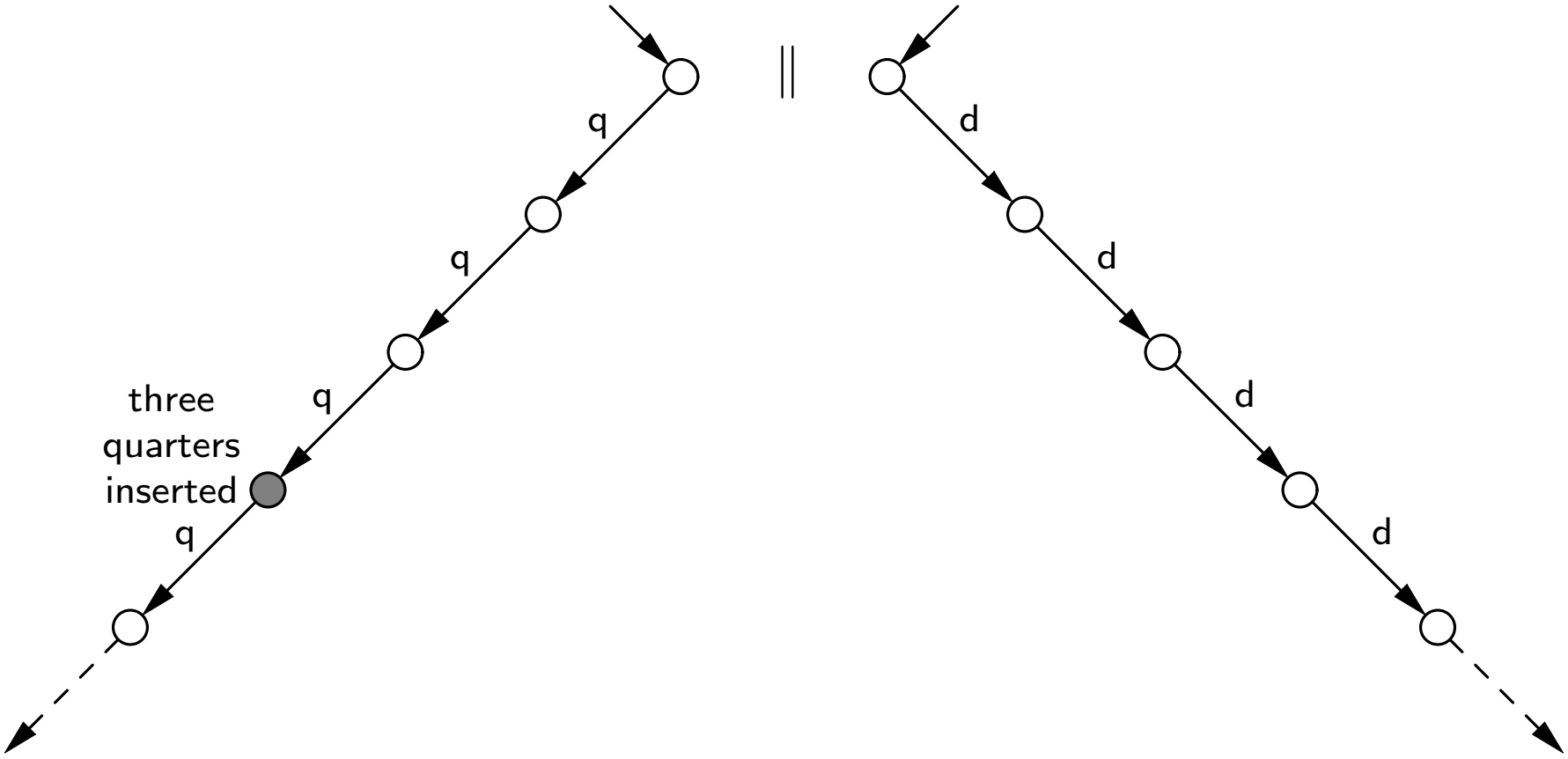

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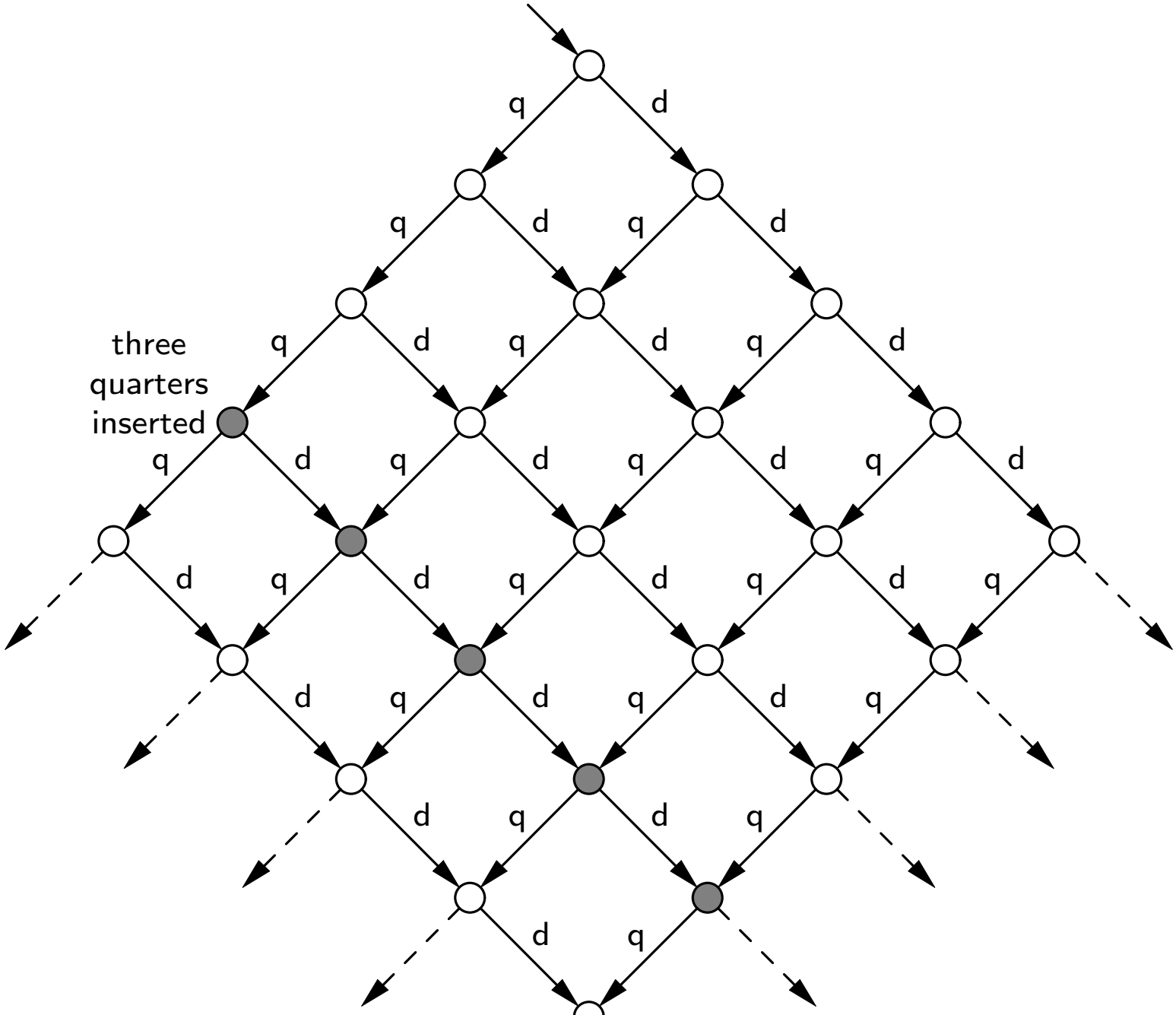

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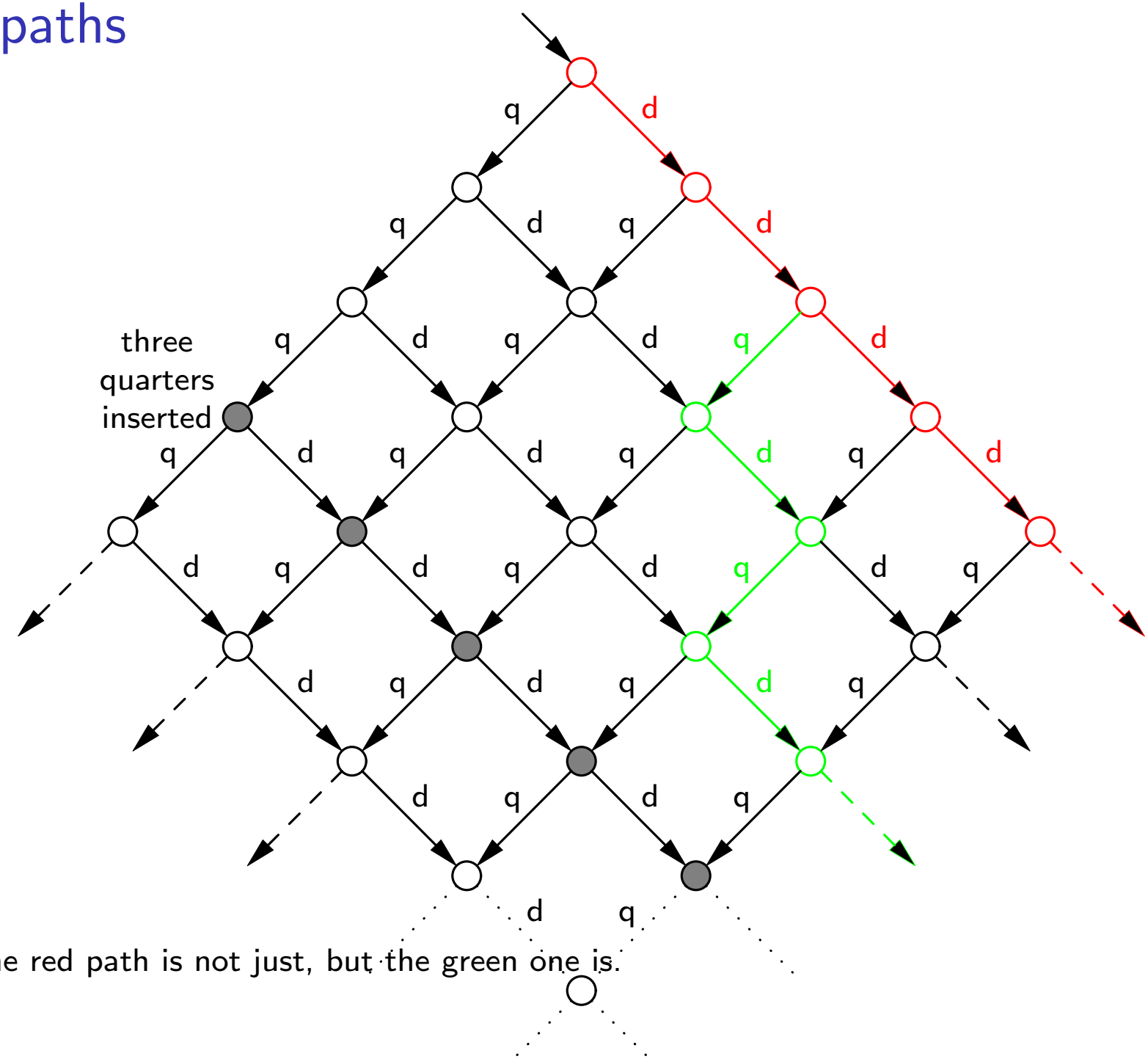

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Concurrency versus competition

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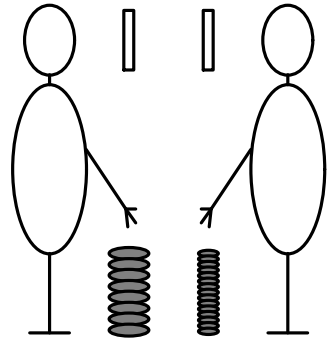

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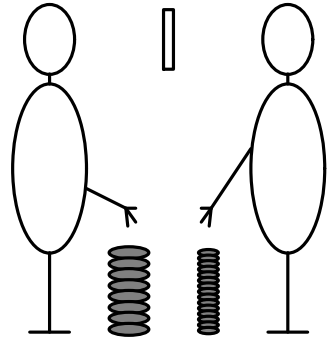

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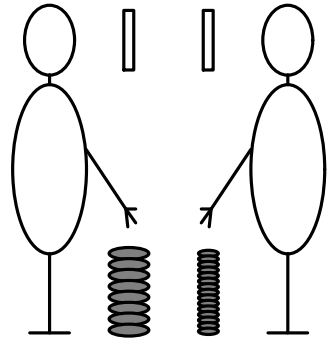

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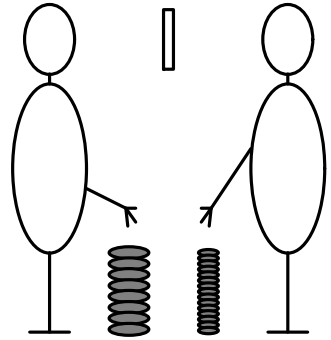

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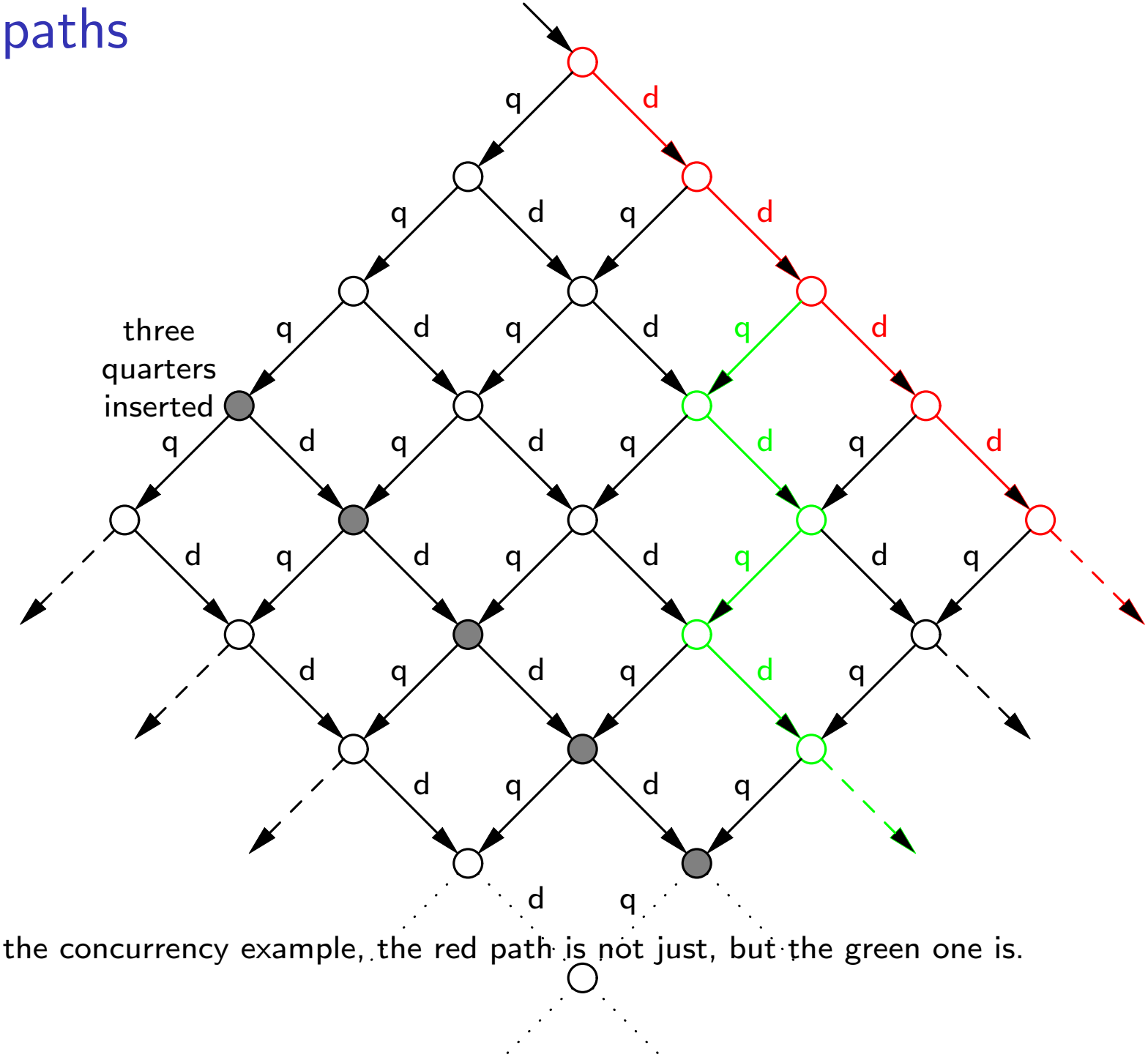

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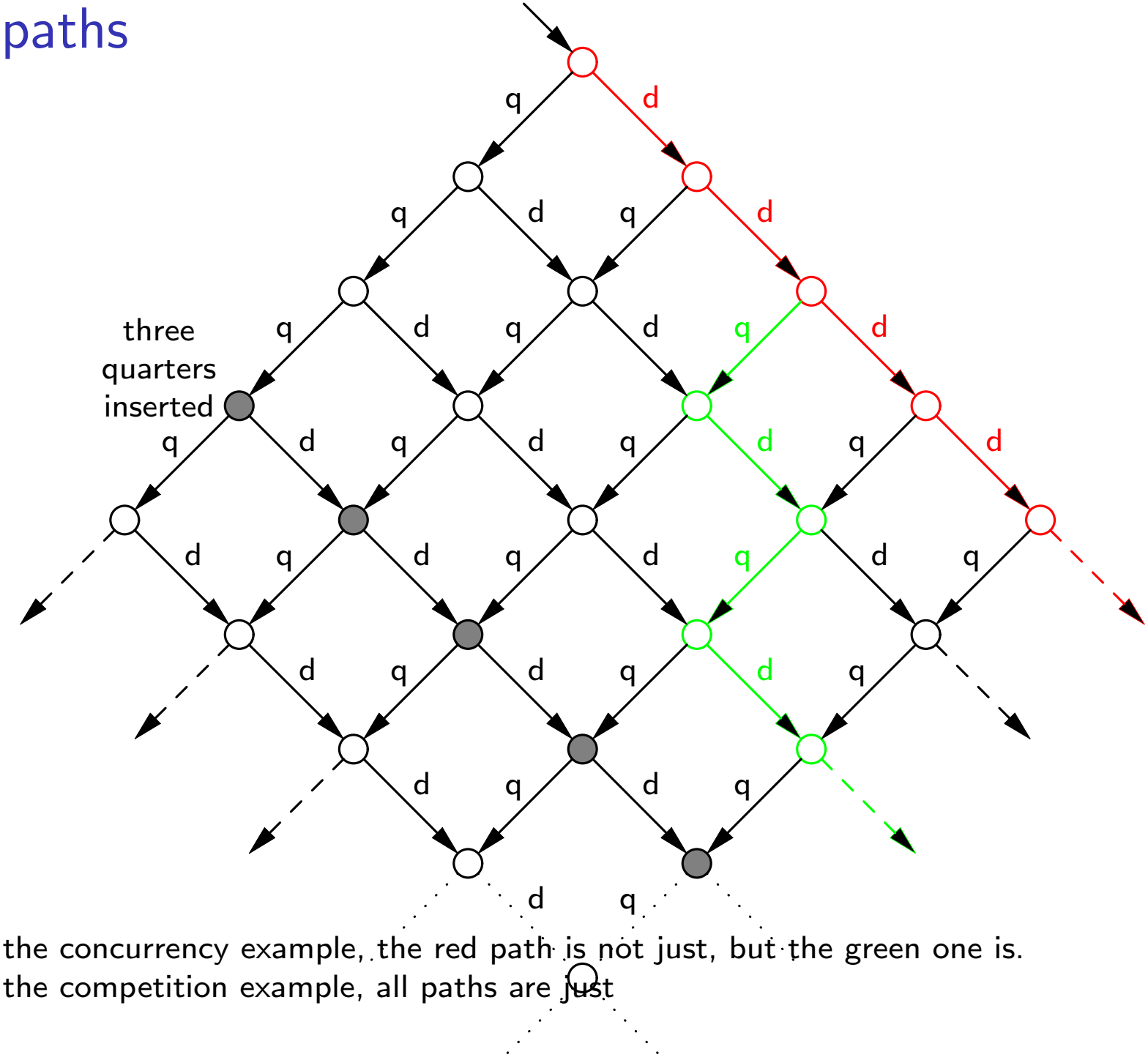

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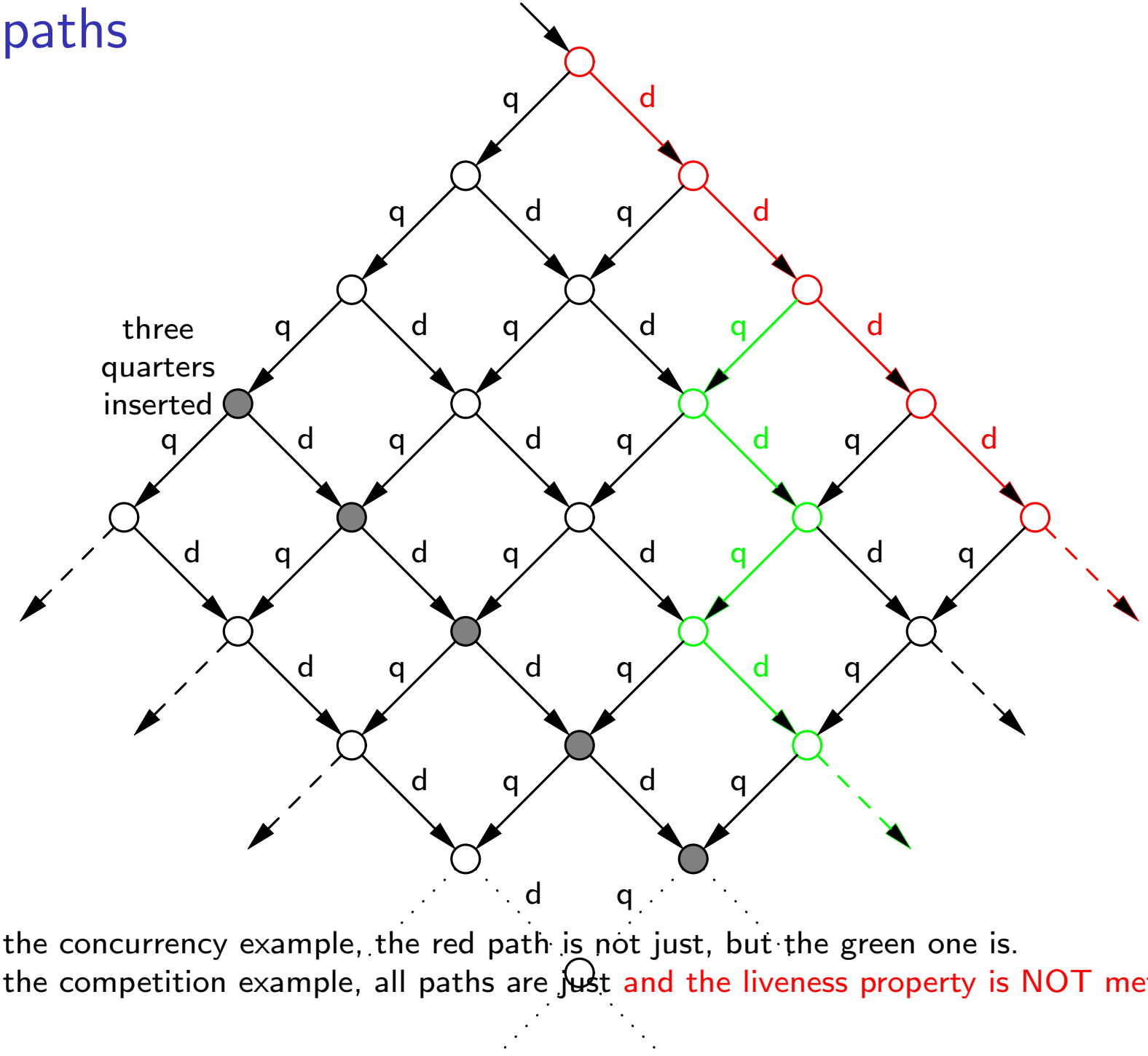

In the concurrency example, the red path is not just, but the green one is.
In the competition example, all paths are just and the liveness property is NOT met.

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Much contemporary research fails to distinguish justness and fairness.
This can lead to unwarranted conclusions and system failures.

Research agenda

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More importantly, we need new technologies to perform efficient verifications in this revised setting.

- Model checking (based on temporal logic)
- Induction principles $\leftarrow$ requires new ideas
- Syntactic formats to ensure compositionality

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  Next to abstraction from internal activity, compositionality is the most powerful tool to attack the state-space explosion.
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  Syntactic checks on code are known that guarantee that forms of compositional reasoning are warranted. But such work needs to be redone when factoring in justness.

Transition systems with successors

Transition systems
plus a ternary relation
between transitions

inserting a dime
does not interfere
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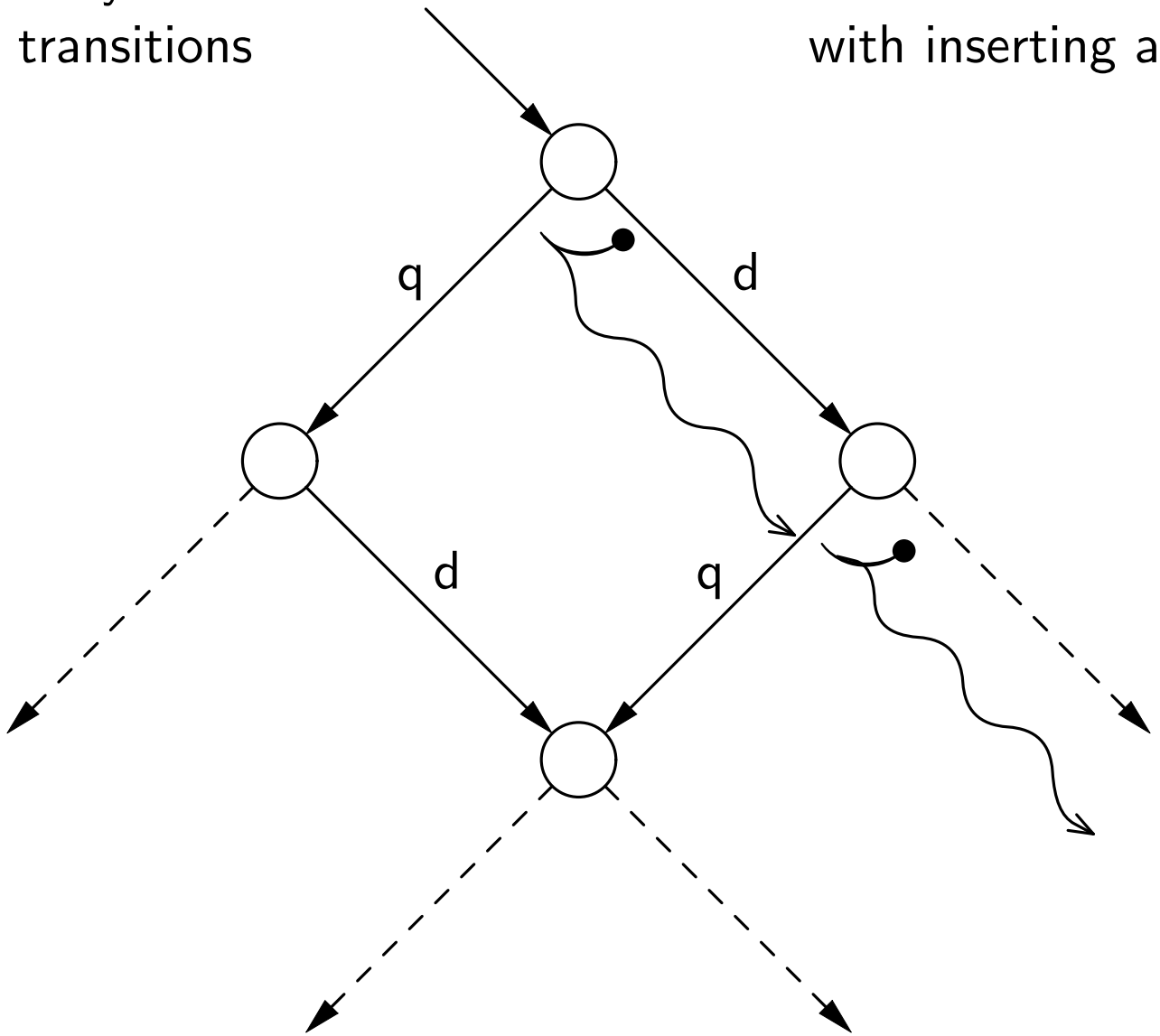

Formalising Justness

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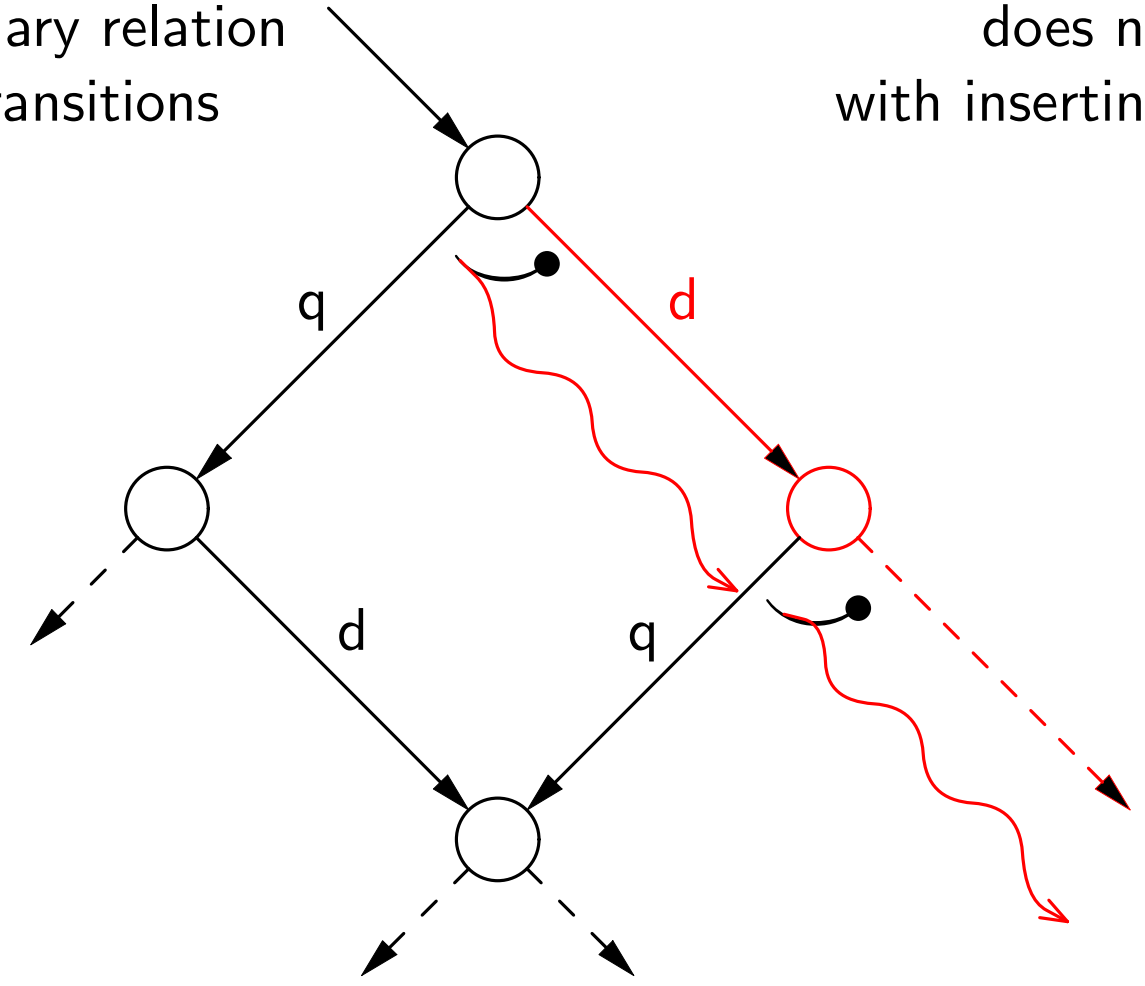

Justness: The system never follows a $\rightarrow$-path
that induces an infinite $\rightsquigarrow$-sequence.

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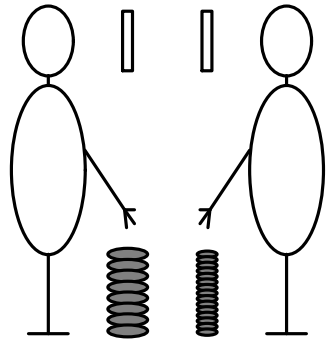

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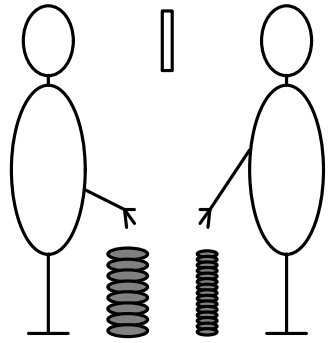

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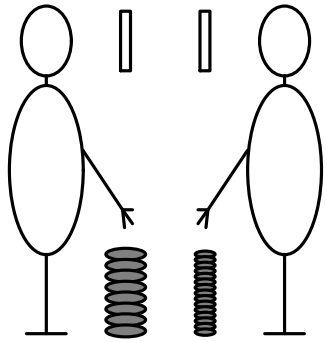

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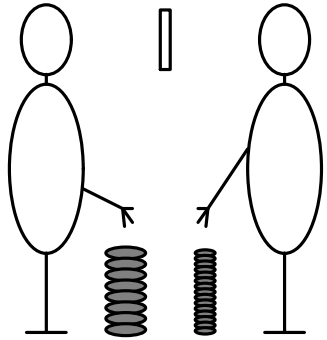

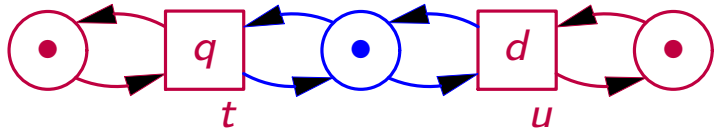

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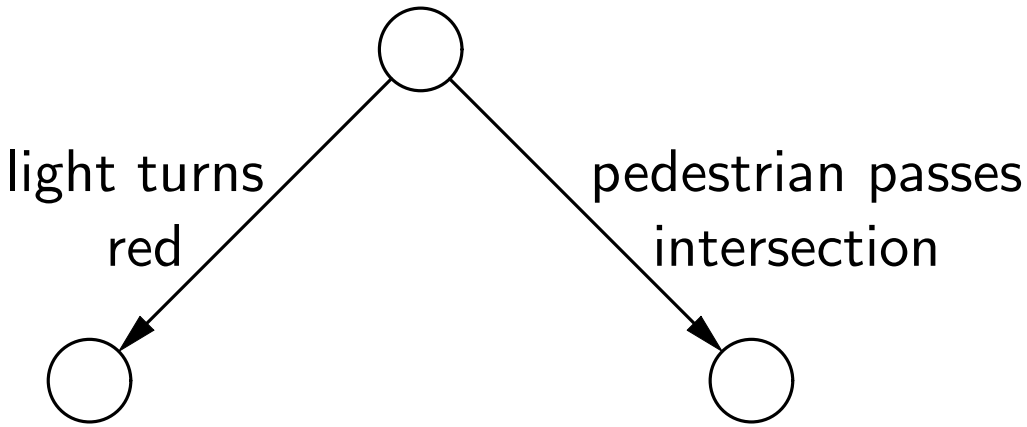
obedient pedestrian approaching a green traffic light



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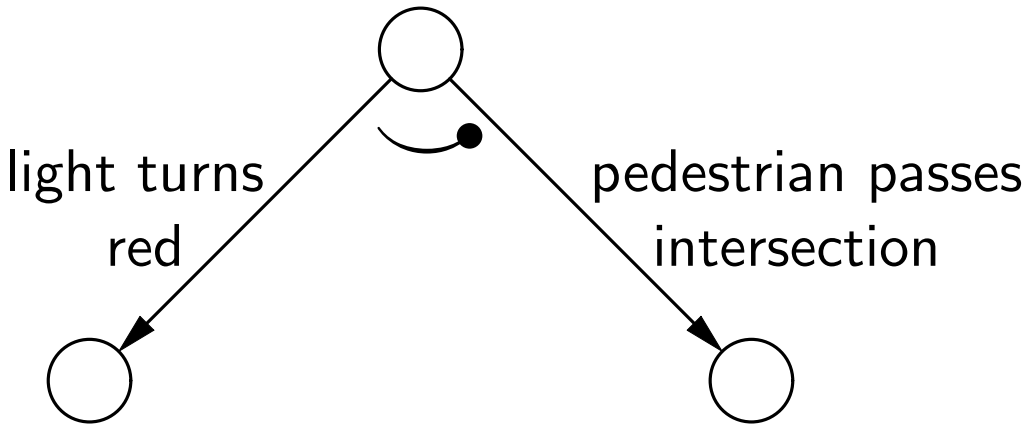

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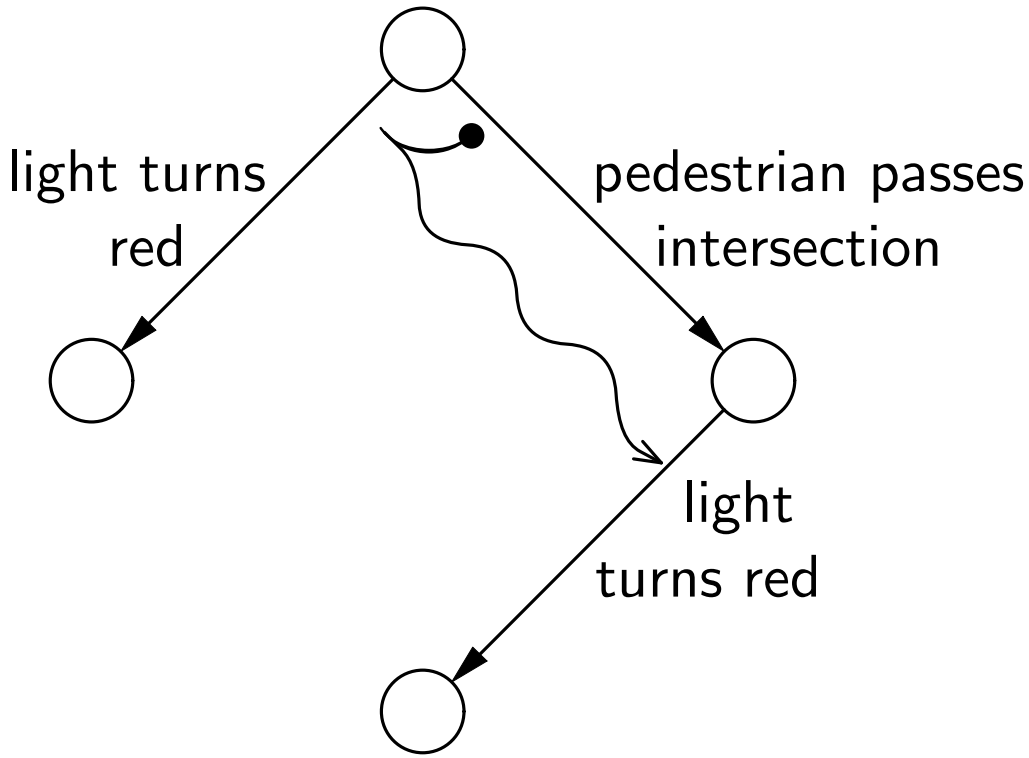

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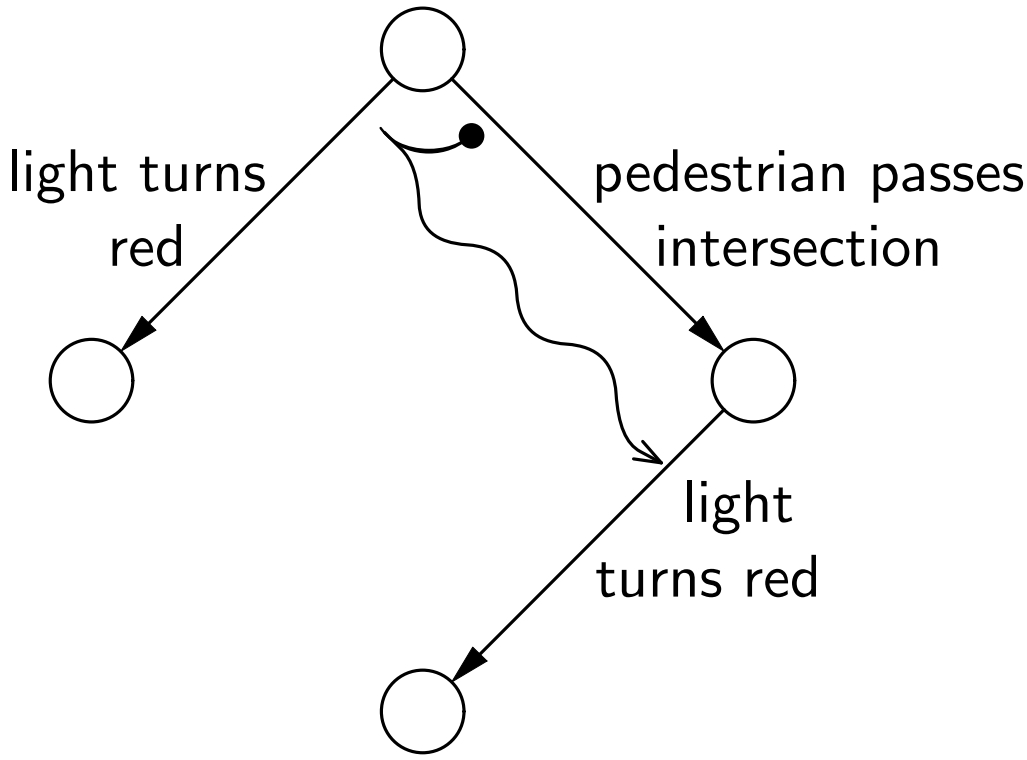

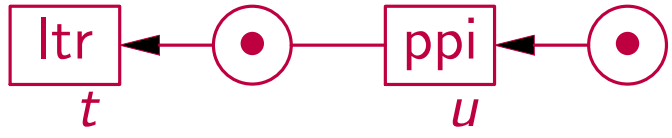

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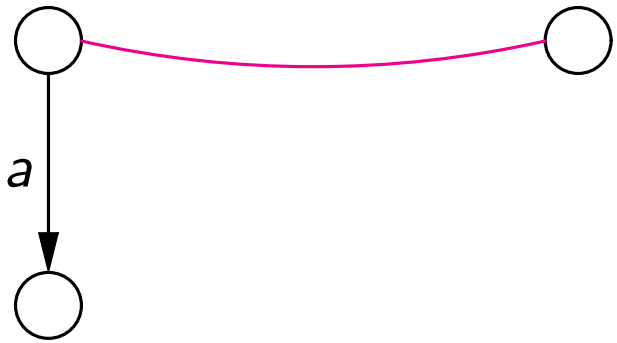
Bisimulation equivalence

To show that two systems have the same properties, one traditionally constructs a *bisimulation* between them. This is a relation $\mathcal{R}$ between their states, such that

- The initial states are related:

- The *transfer property* holds:



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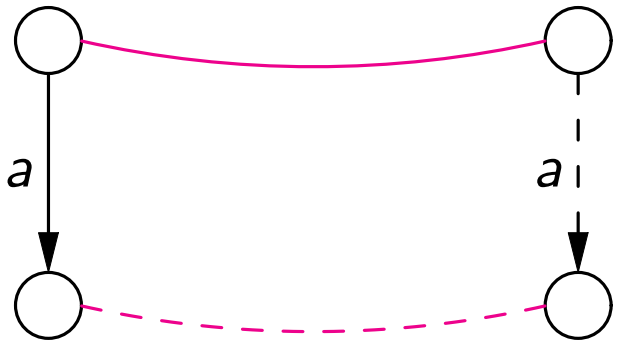

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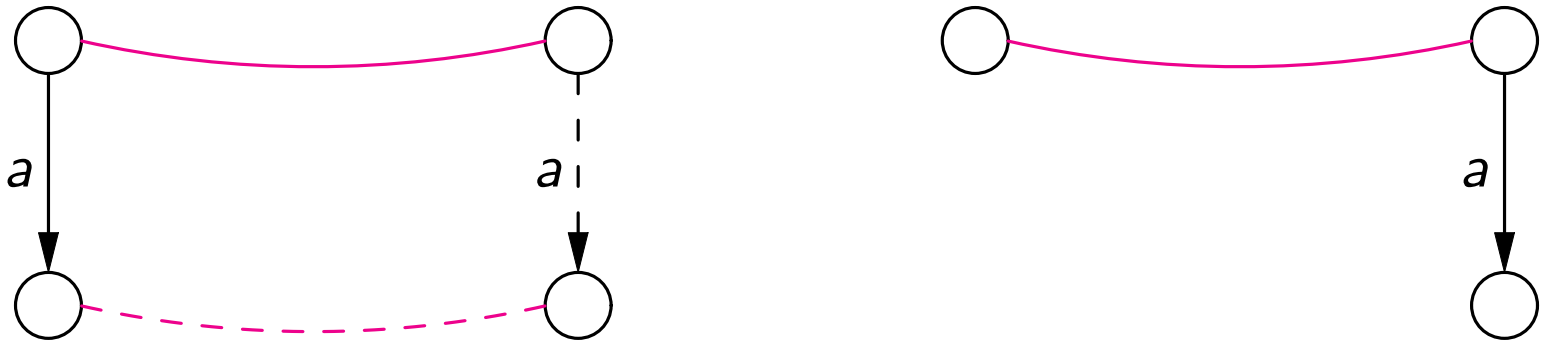

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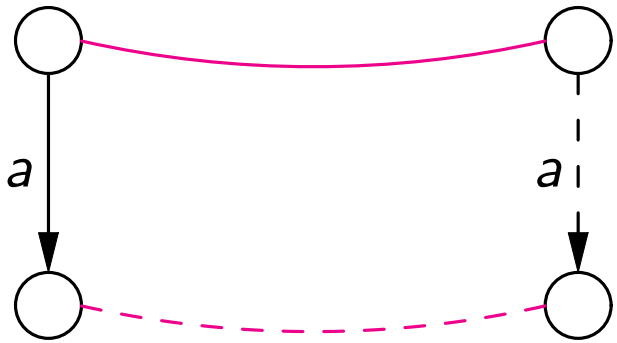
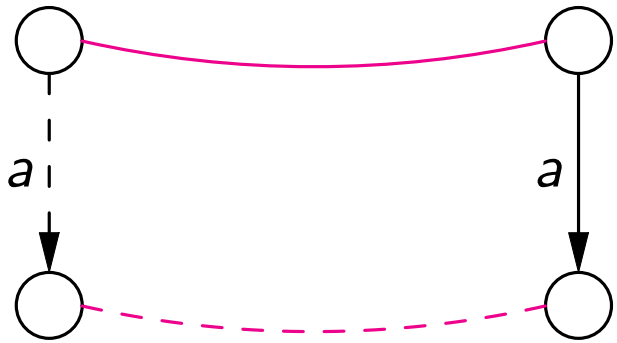


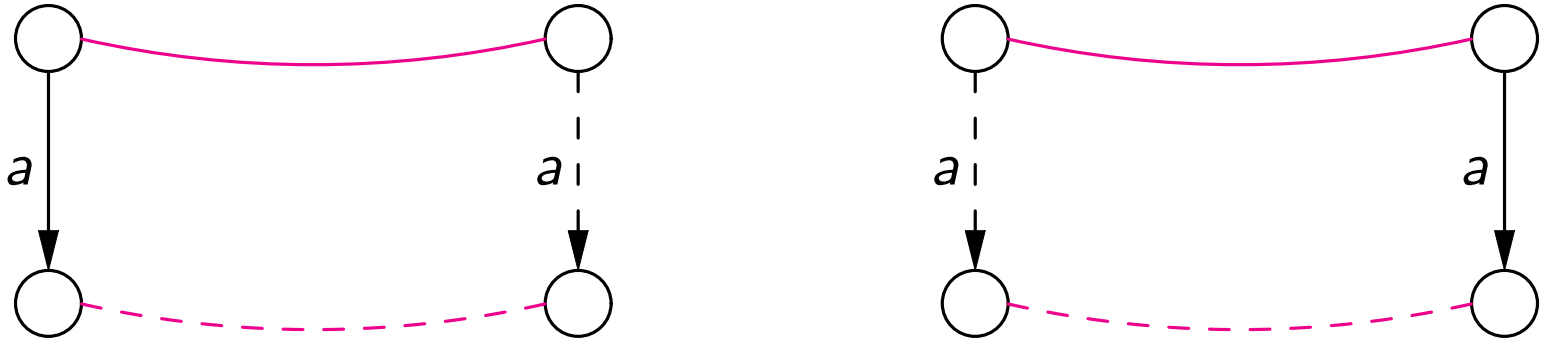


Bisimulation equivalence

To show that two systems have the same properties, one traditionally constructs a *bisimulation* between them. This is a relation $\mathcal{R}$ between their states, such that

- The initial states are related:

- The *transfer property* holds:

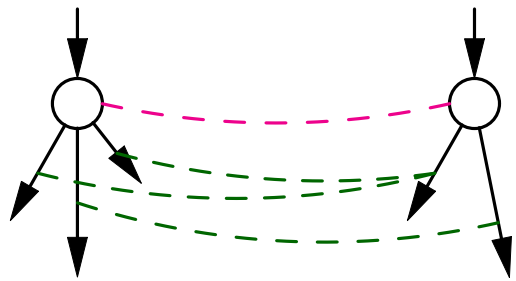


To preserve justness we need a form of bisimulation that also preserves $\rightsquigarrow$.

Enabling preserving bisimulation equivalence

To show that two systems have the same liveness properties, one constructs an *enabling preserving bisimulation* between them.

This is a relation $\mathcal{R}$ between their states, where each pair of related states is equipped with a relation R between their enabled transitions, such that



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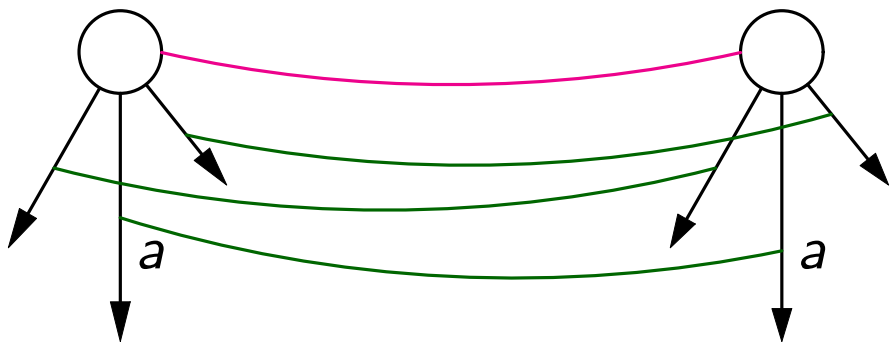

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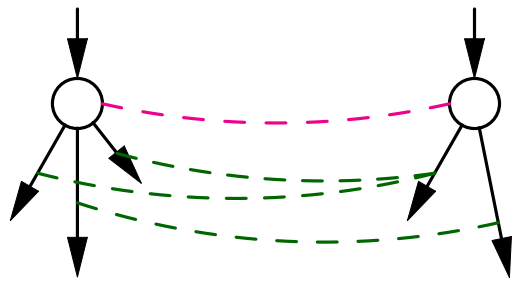

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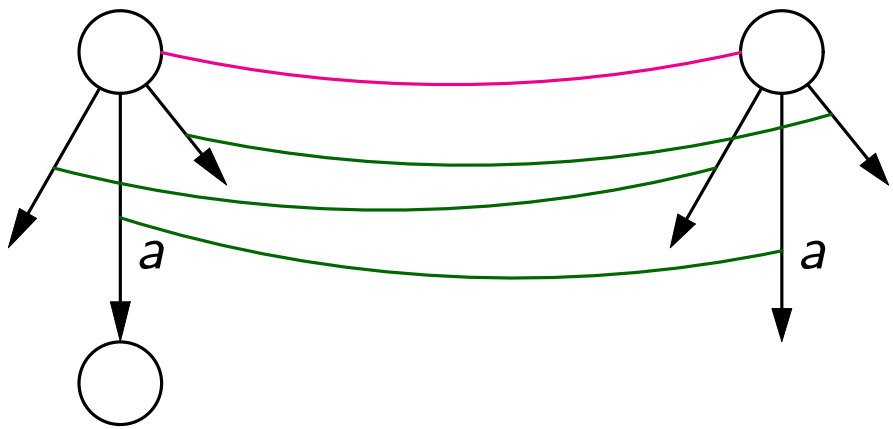

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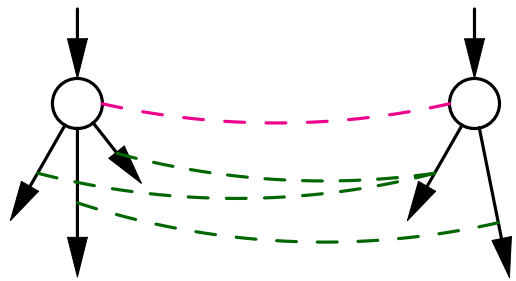

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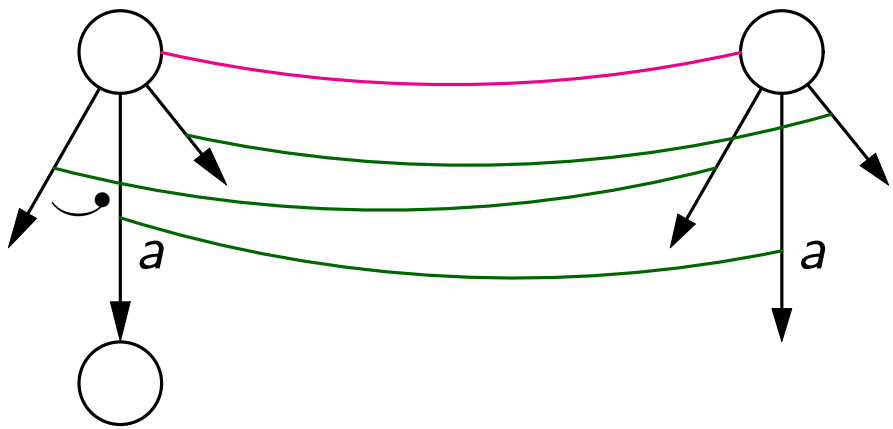

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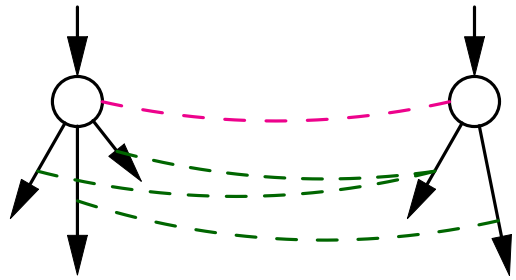

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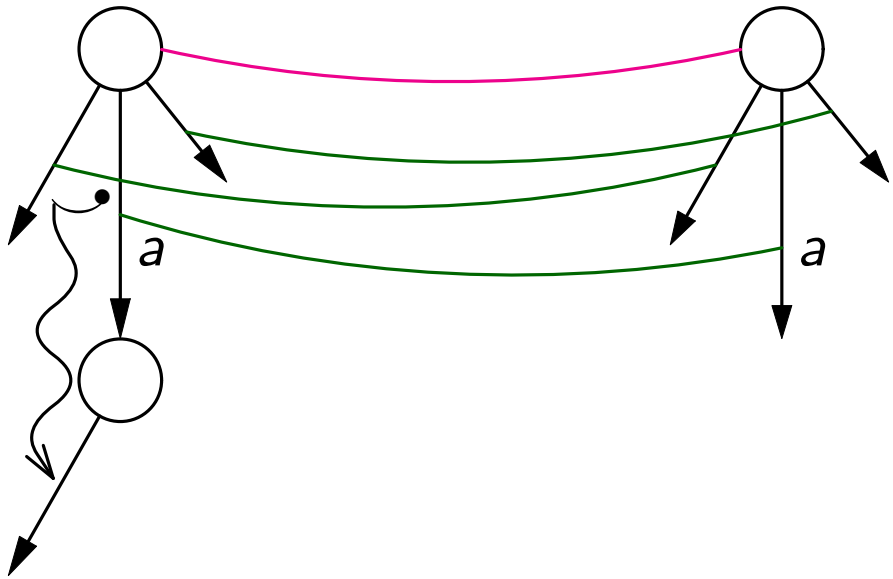

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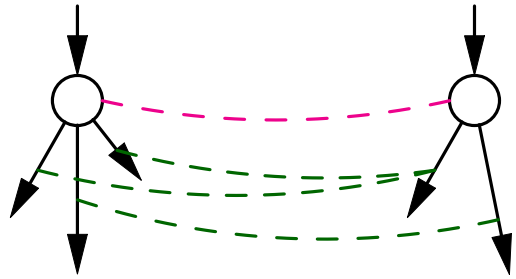

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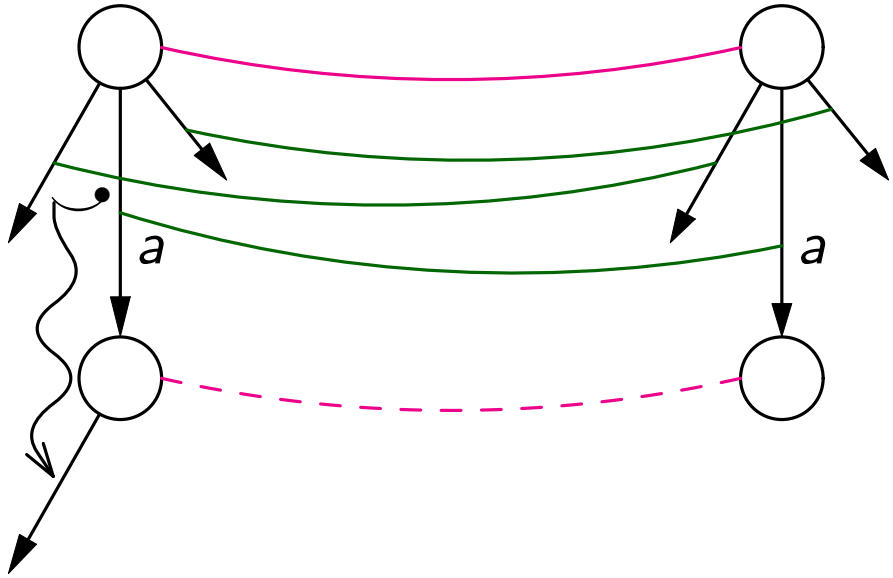

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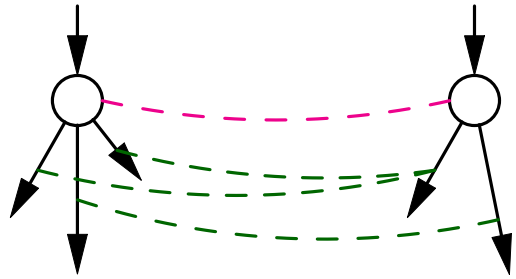

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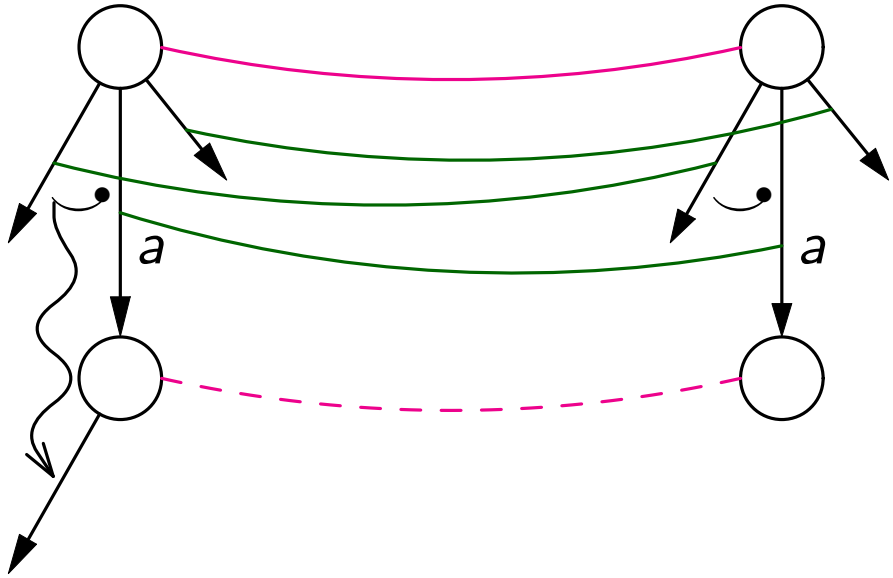

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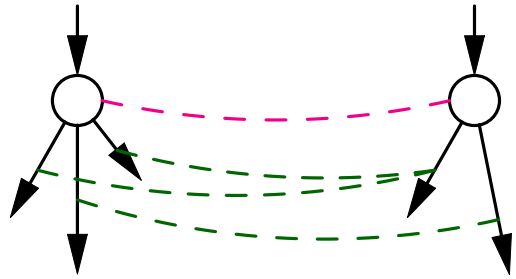

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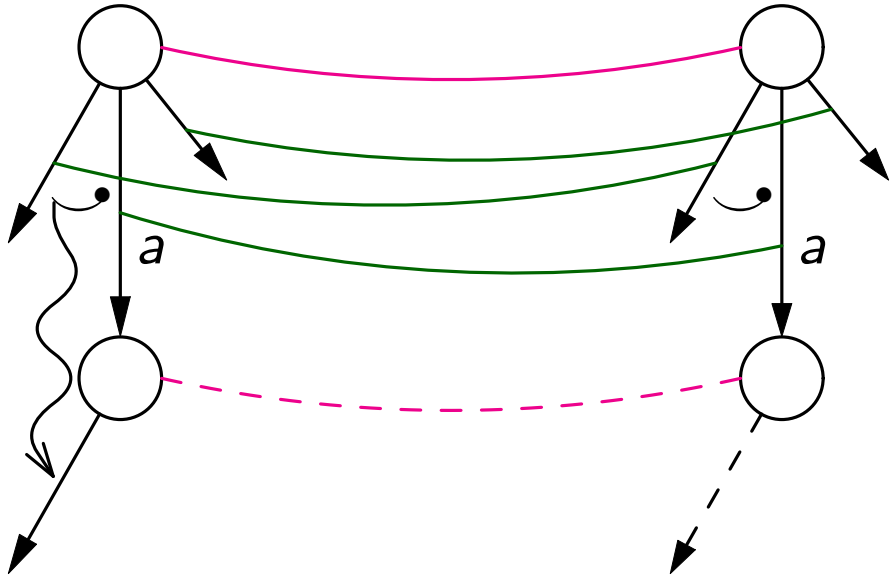

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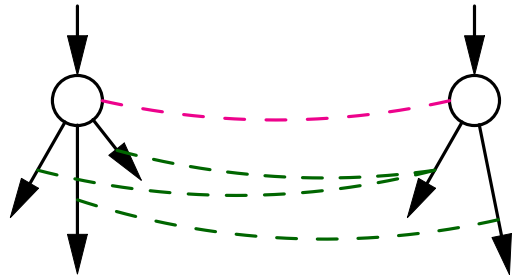

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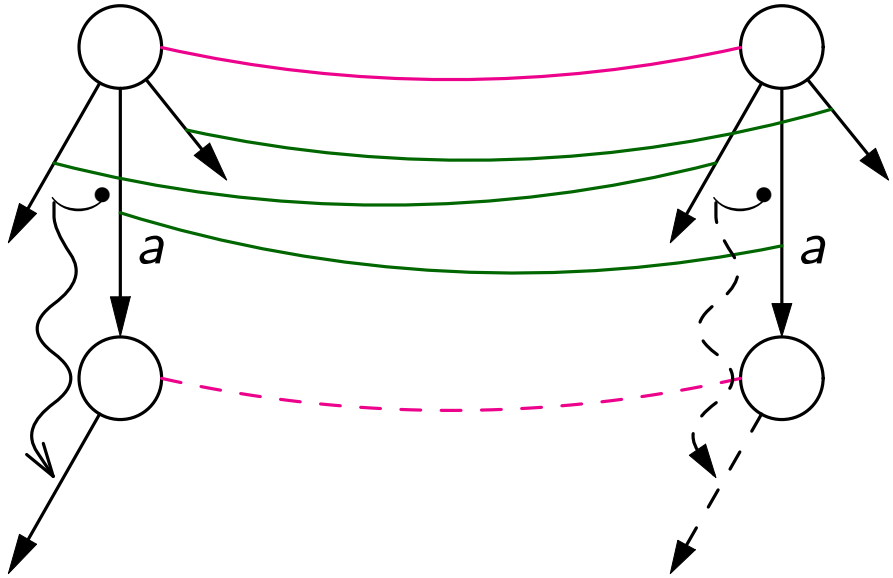

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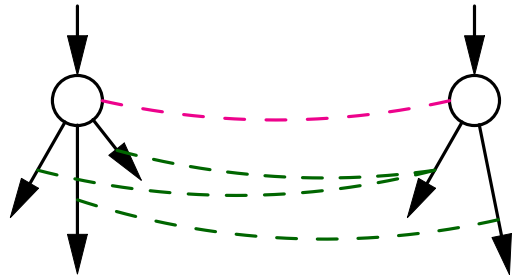

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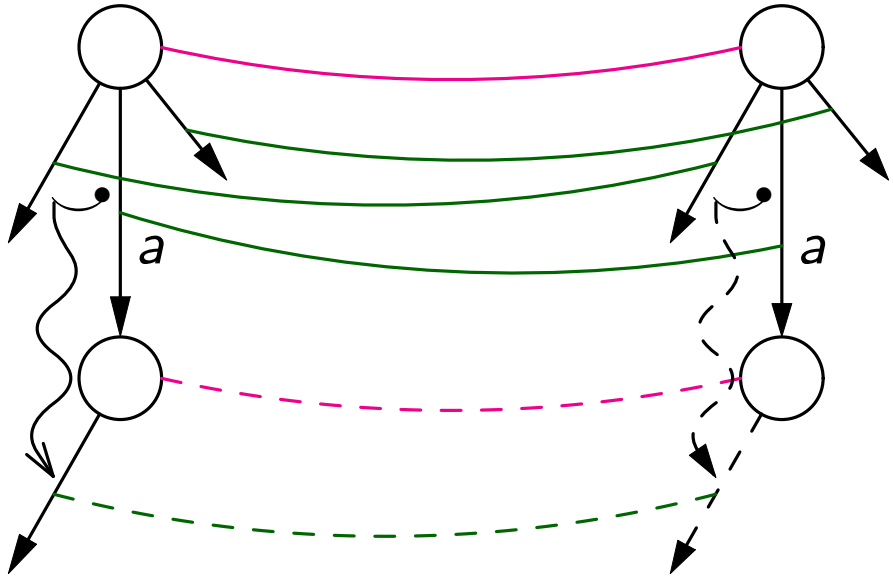

EP bisimulation is useful

This notion of bisimulation has the properties we want:

- it preserves liveness properties
  under the assumption of justness;
- it induces an equivalence relation,
- which is a congruence for parallel composition (and other operators), thus allowing compositional reasoning.

EP bisimulation is useful

This new bisimulation can be used
to prove implementations equivalent to specifications
in such a way that – under the assumption of justness –

all liveness properties of the specification
also hold for the implementation.

Applications: packet delivery

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Here fairness assumptions are not warranted:
they validate versions of packet delivery that do not hold.

Yet, without assuming justness no useful packet delivery property holds.

Applications: locks

Locks take the role of mutual exclusion protocols in efficient implementations of distributed systems.

ticket lock Mellor-Crummey Scott lock Craig Landin Hagersten lock

As for mutex protocols, the correctness properties of such locks require a justness assumption at the least, whereas fairness assumptions can be demonstrated to assume too much.

Moreover, the proposed language extensions come into play.

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Moreover, the proposed language extensions come into play.

Many semi-formal verifications apply the justness assumption implicitly.

I here strive for better reusability through a higher degree for formalisation in which such an assumption becomes explicit.

Applications: garbage collection

In celebrated verifications of garbage collection in software (see, e.g., Gammie et al., PLDI 2015: 99-109), merely safety properties are verified, stating that only garbage will be removed.

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"formal treatment of liveness is likely to be complex [...], given the need for dubious fairness hypotheses."

This is exactly the type of problem that will be solved by my proposed work.