

Self-Stabilizing Disconnected Components Detection and Rooted Shortest-Path Tree Maintenance in Polynomial Steps

Stéphane Devismes¹ David Ilcinkas² Colette Johnen²

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OPODIS 2016
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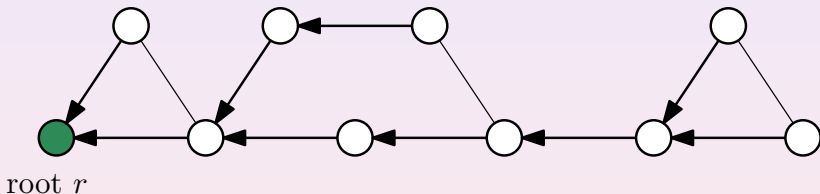
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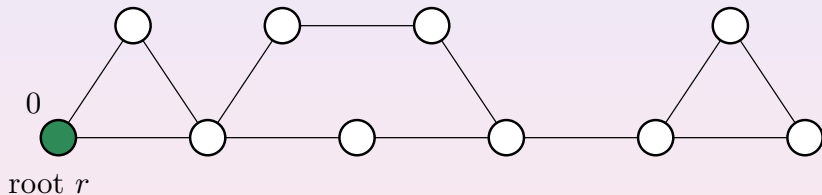
Rooted shortest-path tree

(Framework: distributed computing in networks.)



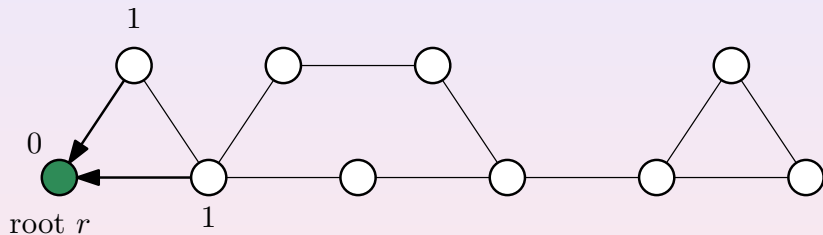
Basically, local knowledge of a **shortest** path to a **fixed** node.

Bellman-Ford Algorithm



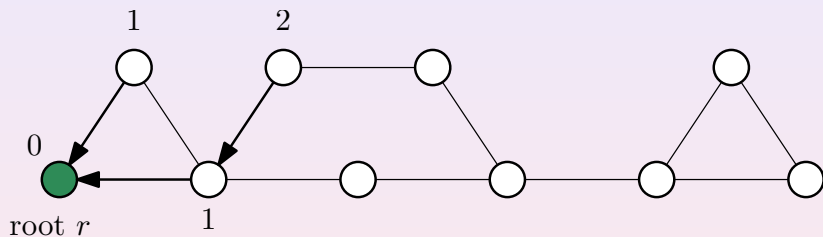
Distributed propagation of distances from the root.

Bellman-Ford Algorithm



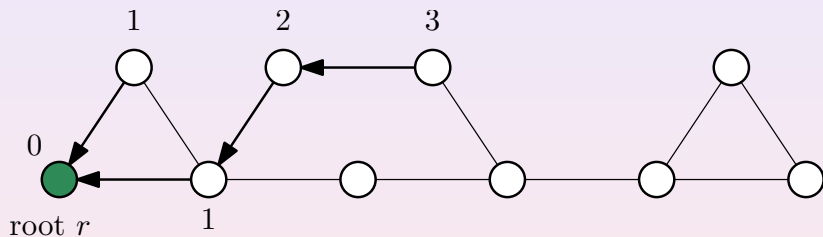
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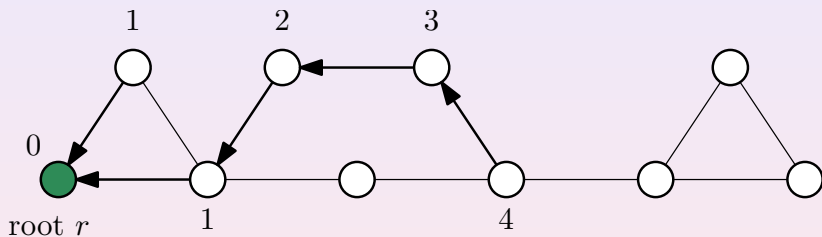
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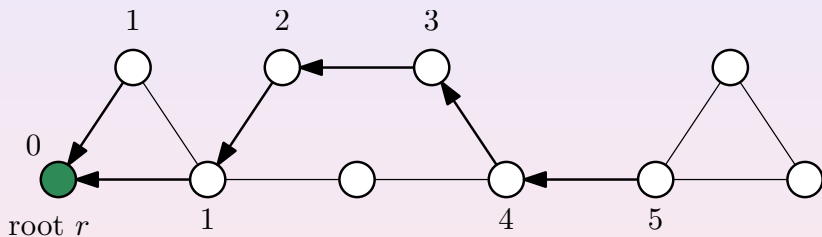
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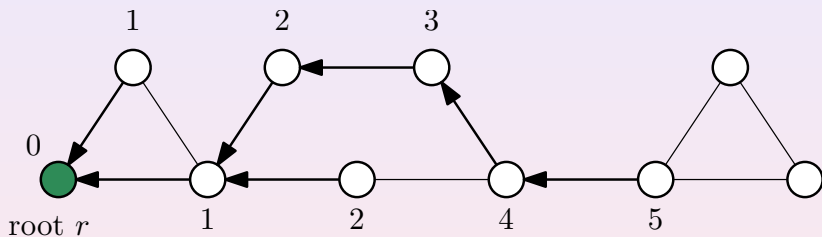
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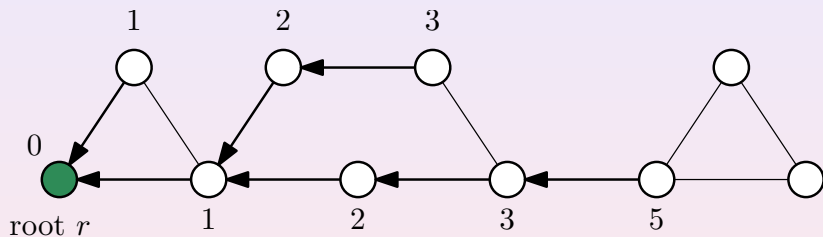
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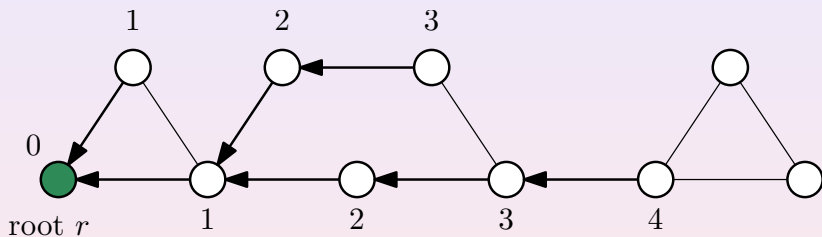
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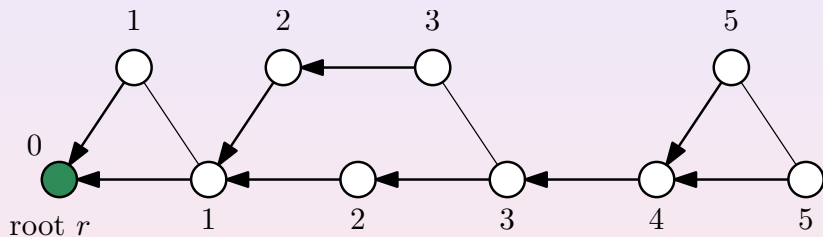
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Distributed propagation of distances from the root.

Motivations

Classical building block for **routing in networks** ...

- In shortest-path routing schemes (like BGP)
- In compact routing schemes

... and in **distributed algorithms** in general.

In practice

- The network may change over time (faults, updates, etc.)
- The network may be even disconnected

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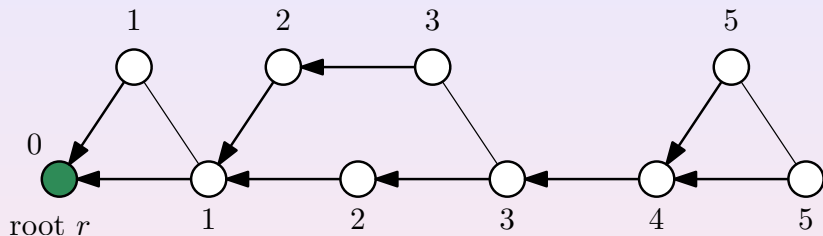
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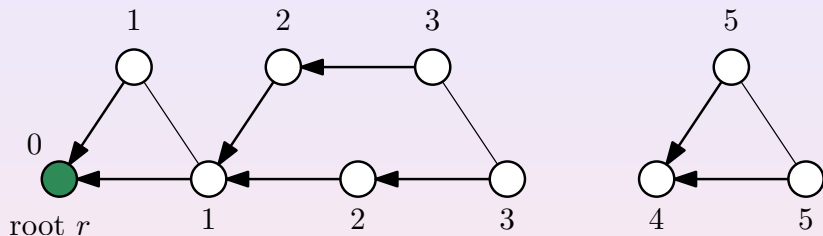
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Count-to-infinity problem



- Bandwidth is uselessly consumed.
- Basic update mechanism may fail
⇒ useless control messages.

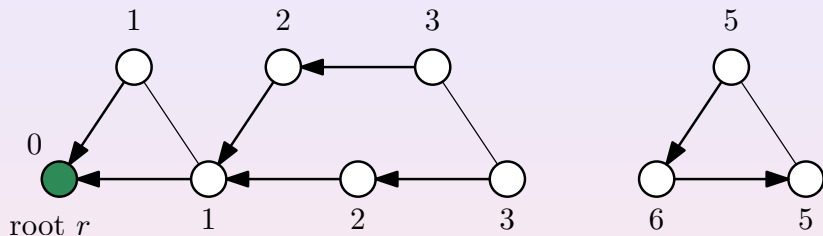
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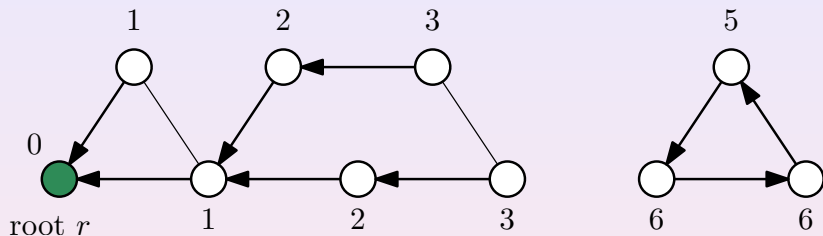
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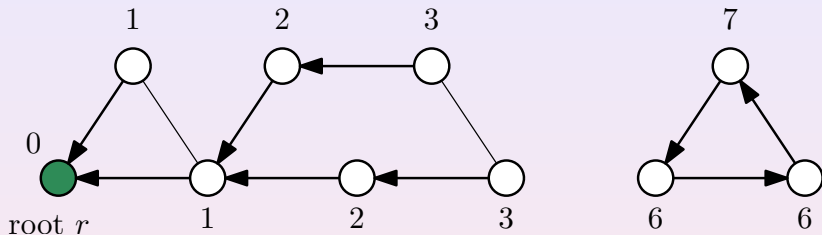
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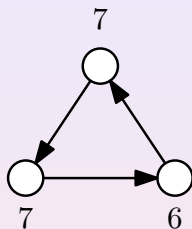
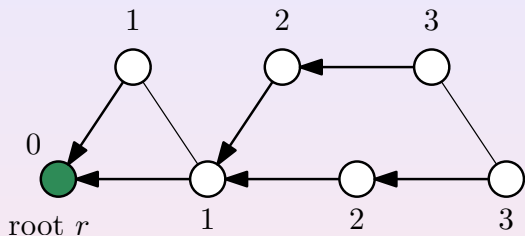
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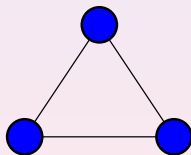
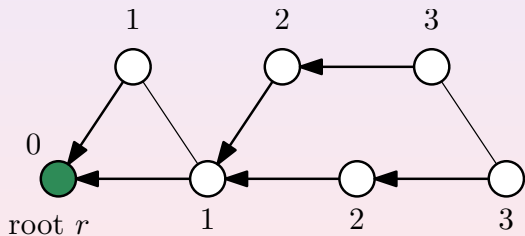
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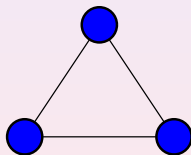
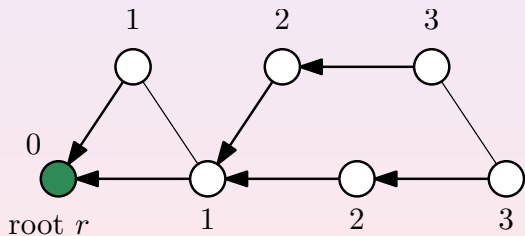
The problem at hand

Disconnected Components Detection and
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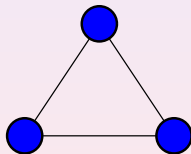
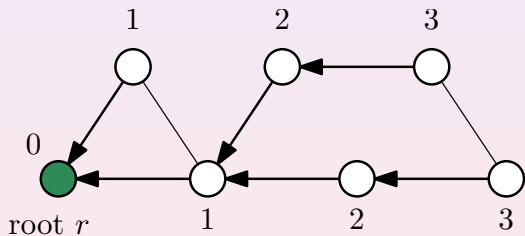
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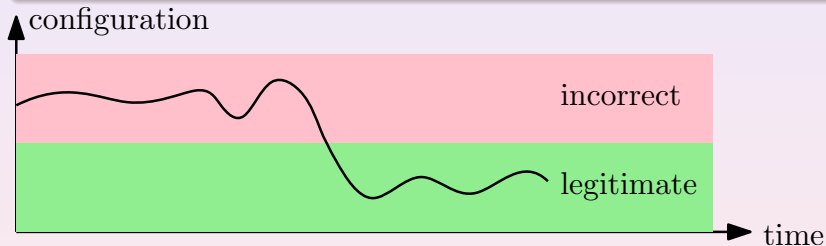
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Self-Stabilization

Definition

A **self-stabilizing** distributed system will **eventually behave correctly** no matter its **initialization**.



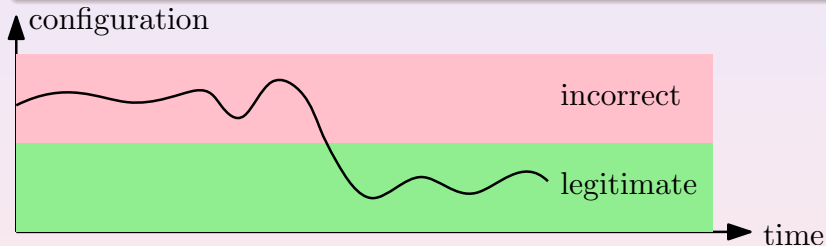
Context of use

- Transient faults
- Low-rate dynamics

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Model (1/2)

Classical model, introduced by Dijkstra [Commun. ACM, 1974]

Locally shared memory model. . .

Each node u has **local variables** that can be

- read by u and its neighbors,
- written only by u

with composite atomicity

The state of a node is updated based on the local neighborhood in an atomic step.

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Model (2/2)

Program of a node

List of rules **Guard** \rightarrow **Action** for node u

- Guard: function of the variables of u and its neighbors
- Action: update of the local variables

Enabled

- A rule is enabled if its guard evaluates to true.
- A node is enabled if at least one of its rules is enabled.

Step and daemon (asynchrony)

At each step, the daemon must select at least one enabled node to be executed.

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Our results

Main contribution

We propose and prove a **self-stabilizing** algorithm solving the **DCDSPM** problem with the following properties

- It works under *any daemon* (the unfair daemon).
- The algorithm is *silent*: eventually, no states are changed.
- Edges may have arbitrary *positive weights*.
- No *a priori* knowledge on global parameters (like n or D).
- *Linear in rounds*: $3n_{\max\text{CC}} + D$.
- *Polynomial in steps*: $O(W_{\max} n_{\max\text{CC}}^3 n)$.

- n : total number of nodes
- D : (hop-)diameter of the network
- $n_{\max\text{CC}}$: max. number of nodes in a connected component
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Related work

DCDSPM

- [Glacet, Hanusse, Ilcinkas, Johnen, 2014]
 $2n_{\max CC} + D$ rounds but **exponential #steps**

Shortest-path spanning tree (no analyses for #steps)

- [Many papers]

Disjunction

- [Datta, Devismes, Larmore, 2012]
 \approx DCDSPM with uniform weights but **exponential #steps**

BFS-tree (restricted to polynomial #steps)

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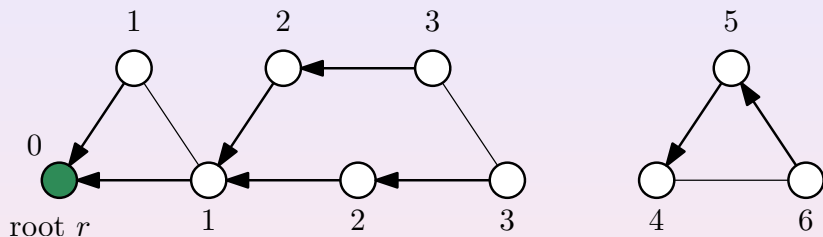
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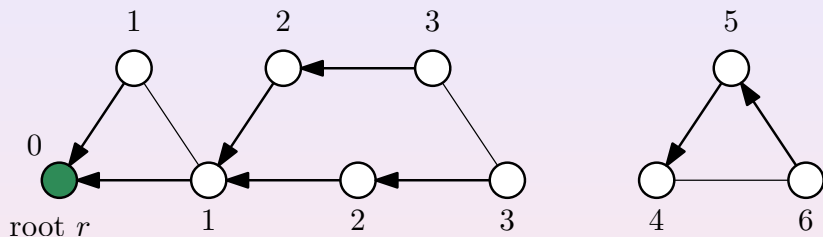
Ideas behind the algorithm



To be pretty cautious...

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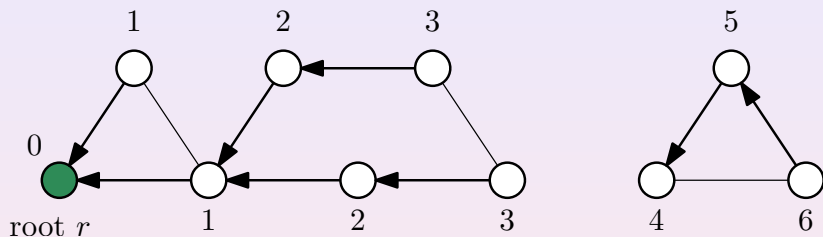
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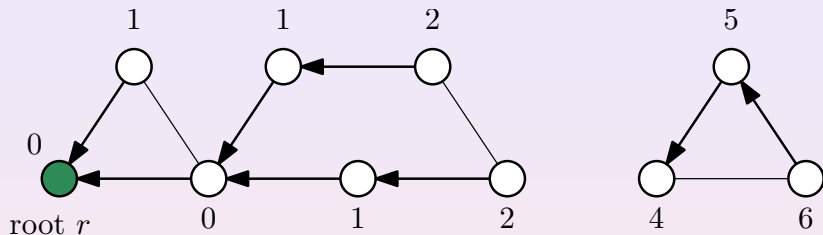
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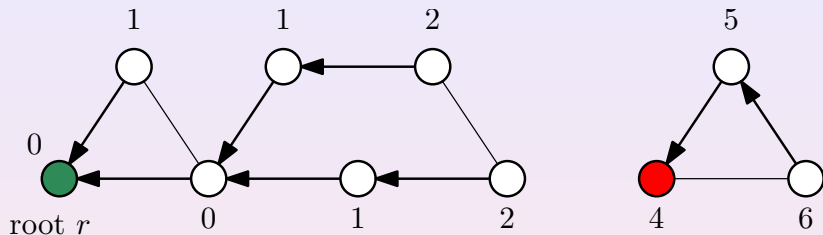
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1 wave (1 error state) gives a correct but exponential algorithm
[Glacet, Hanusse, Ilcinkas, Johnen, 2014]

Two waves allow a polynomial number of steps.
But $n_{\max CC}$ additional rounds.

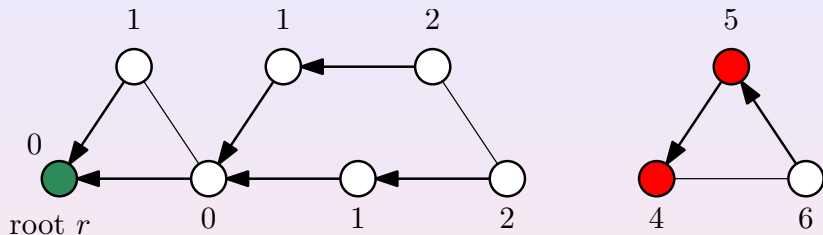
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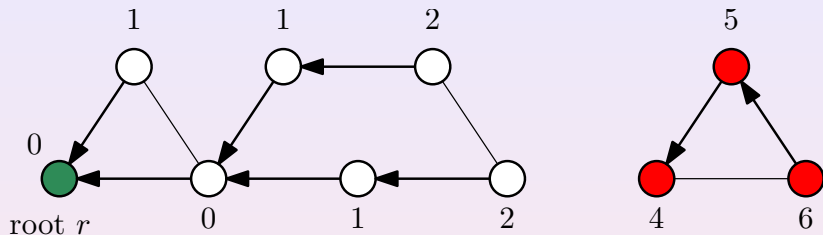
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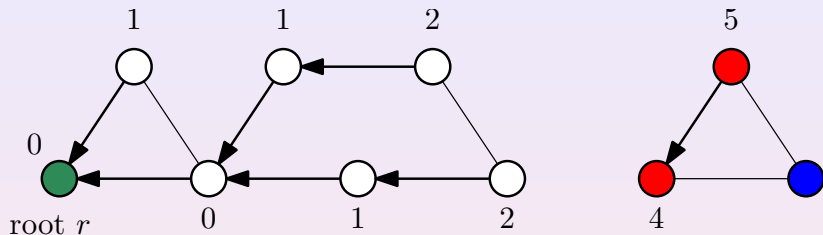
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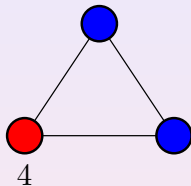
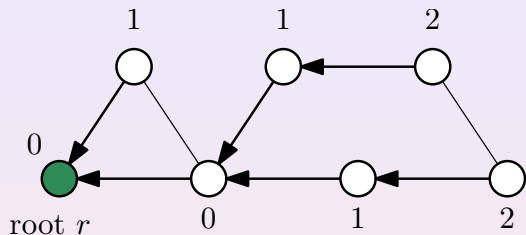
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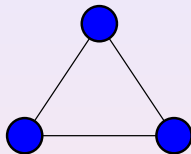
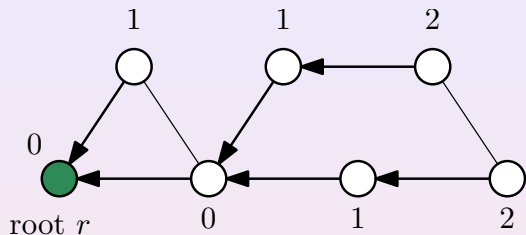
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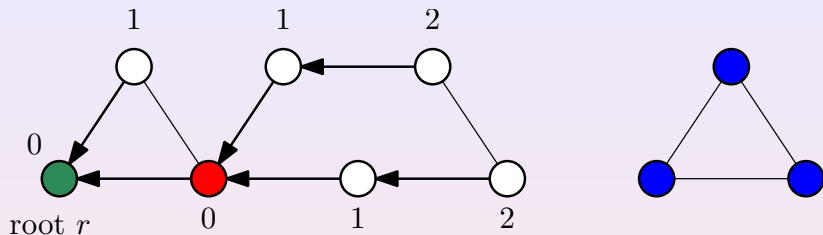
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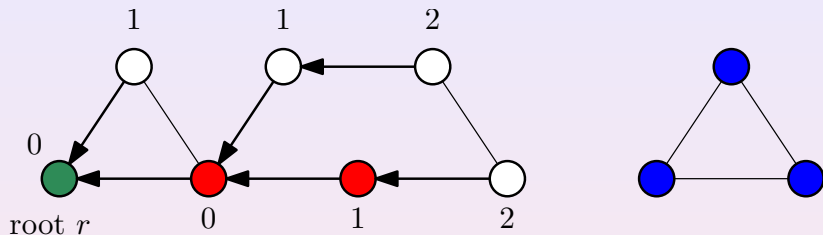
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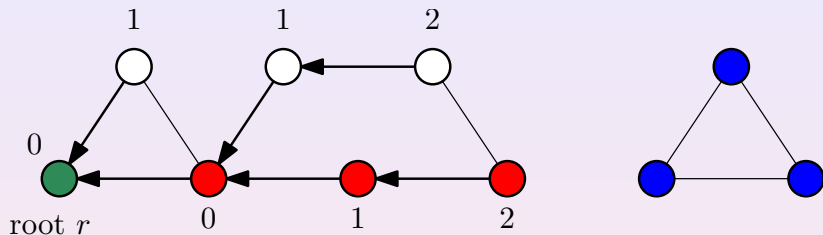
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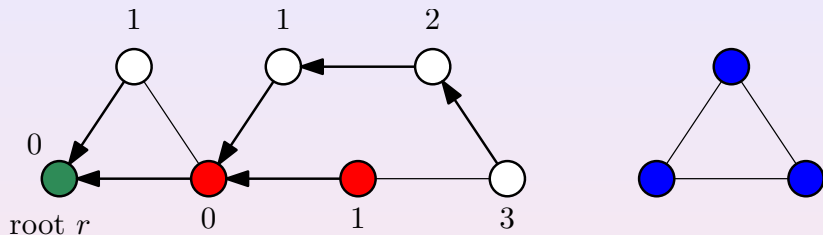
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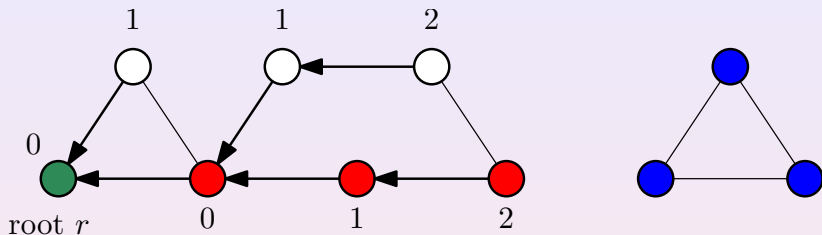
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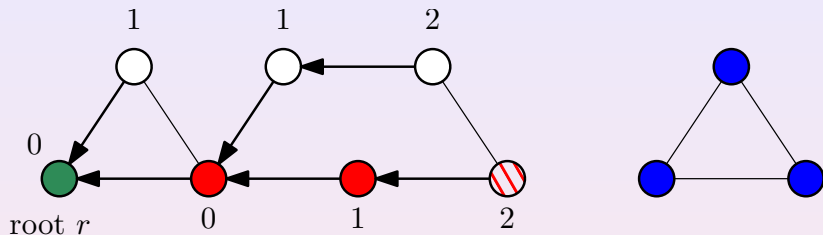
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[Glacet, Hanusse, Ilcinkas, Johnen, 2014]

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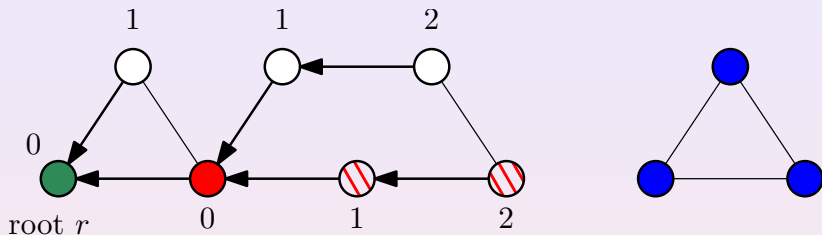
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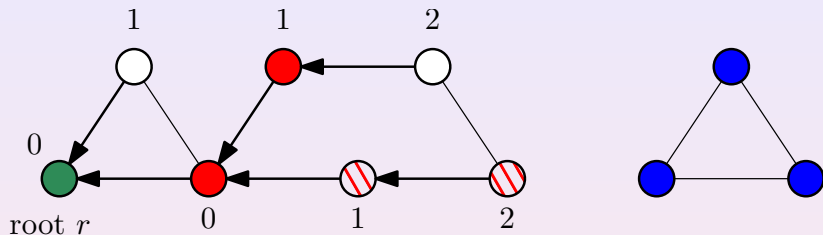
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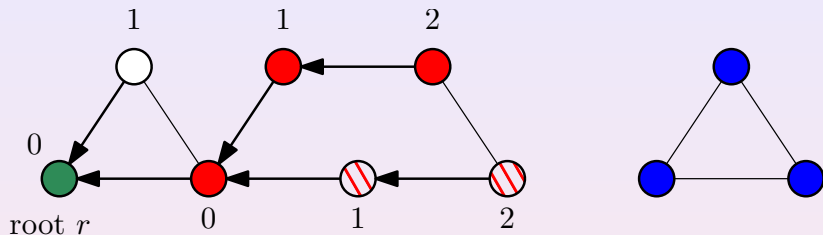
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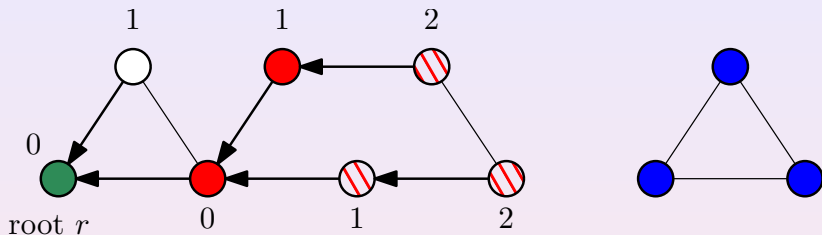
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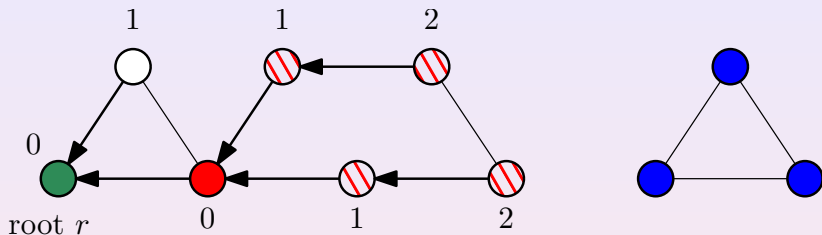
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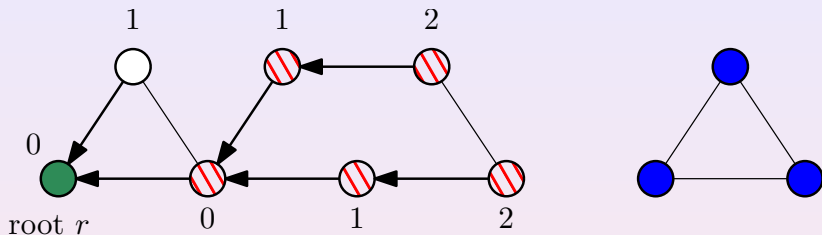
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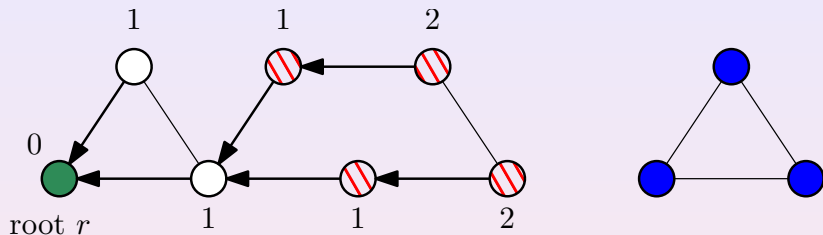
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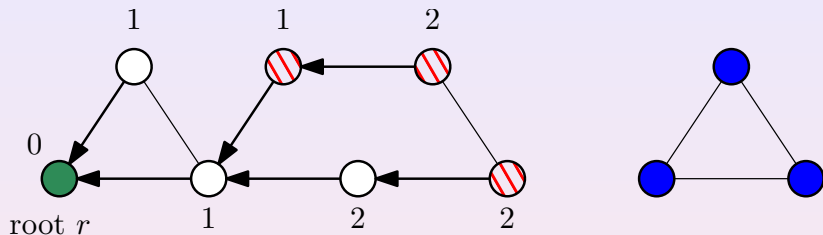
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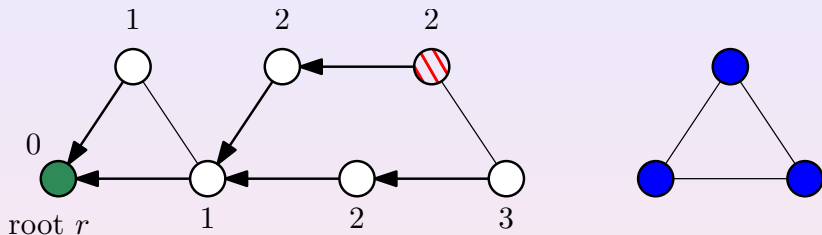
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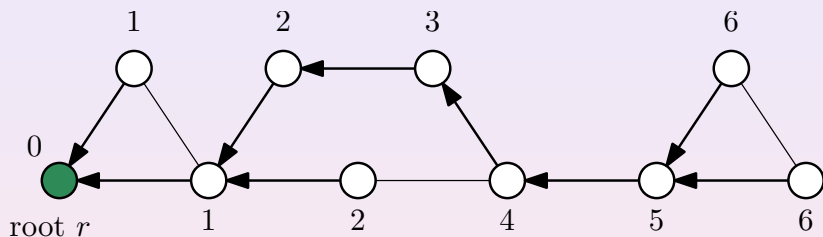
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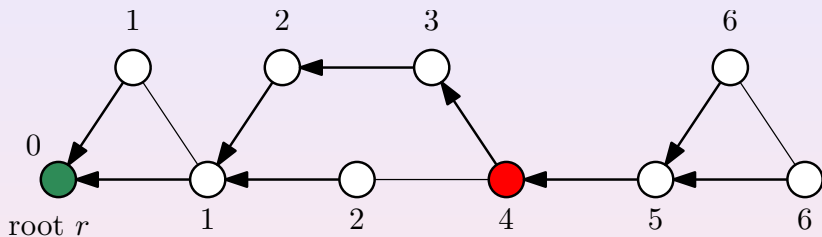
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... but not too much



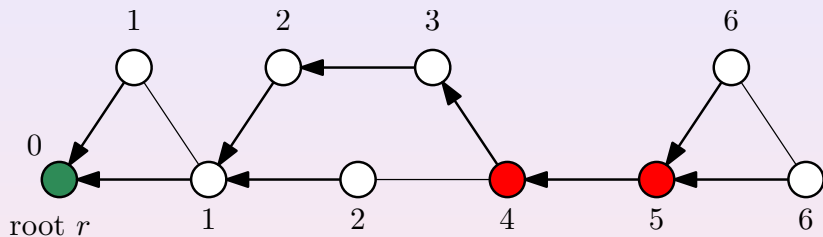
Not directly improving distances leads to $\Omega(D^2)$ rounds.

... but not too much



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Formal algorithm

Algorithm 2: Code of RSP for any process $u \neq r$

Variables:

$st_u \in \{I, C, EB, EF\}$

$par_u \in Lbl$

$d_u \in \mathbb{N}^*$

Predicates:

$P_reset(u) \equiv st_u = EF \wedge abRoot(u)$

$P_correction(u) \equiv (\exists v \in \Gamma(u) \mid st_v = C \wedge d_v + \omega(u, v) < d_u)$

Macro:

$computePath(u) : par_u := \operatorname{argmin}_{(v \in \Gamma(u) \wedge st_v = C)} (d_v + \omega(u, v));$
 $d_u := d_{par_u} + \omega(u, par_u);$
 $st_u := C$

Rules

$\mathbf{R}_C(u) : st_u = C \wedge P_correction(u) \rightarrow computePath(u)$

$\mathbf{R}_{EB}(u) : st_u = C \wedge \neg P_correction(u) \wedge (abRoot(u) \vee st_{par_u} = EB) \rightarrow st_u := EB$

$\mathbf{R}_{EF}(u) : st_u = EB \wedge (\forall v \in children(u) \mid st_v = EF) \rightarrow st_u := EF$

$\mathbf{R}_I(u) : P_reset(u) \wedge (\forall v \in \Gamma(u) \mid st_v \neq C) \rightarrow st_u := I$

$\mathbf{R}_R(u) : (P_reset(u) \vee st_u = I) \wedge (\exists v \in \Gamma(u) \mid st_v = C) \rightarrow computePath(u)$

Thank you
for your attention