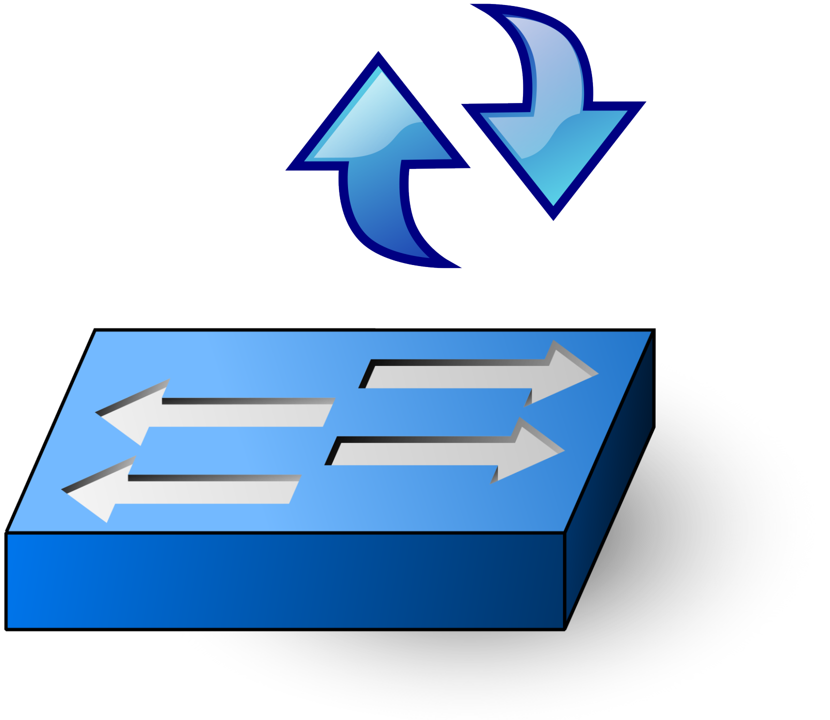
Good Network Updates for Bad Packets

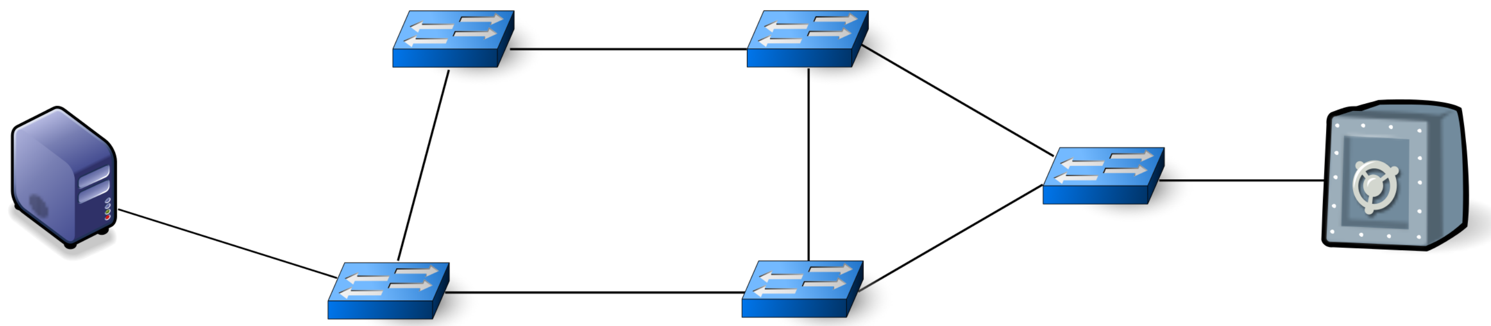
Arne Ludwig,
Matthias Rost, Damien Foucard, Stefan Schmid

Updates happen

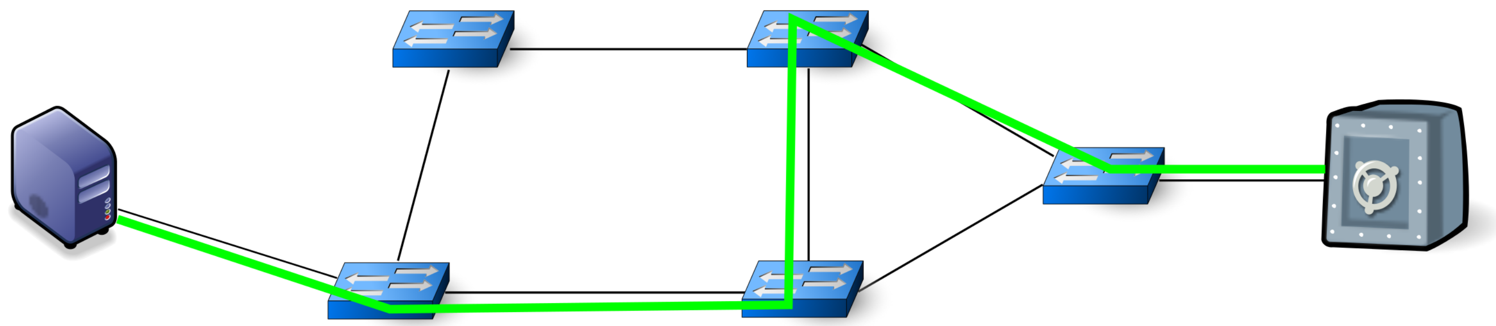
- Network updates happen
  - Changing security policies
- Network updates are challenging
  - Even with global view
- Potential high damage if fail
  - Security policy violation



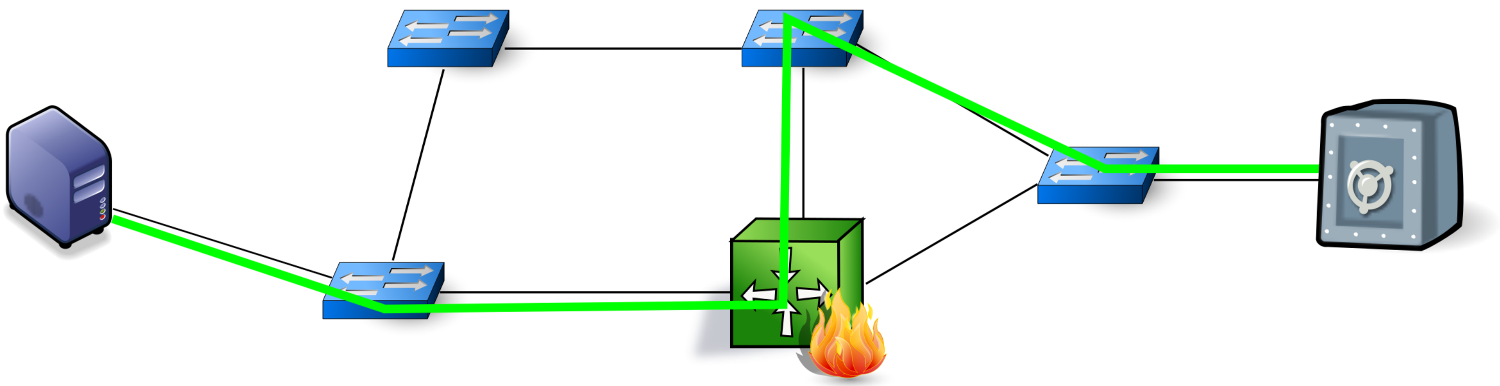
Example



Example

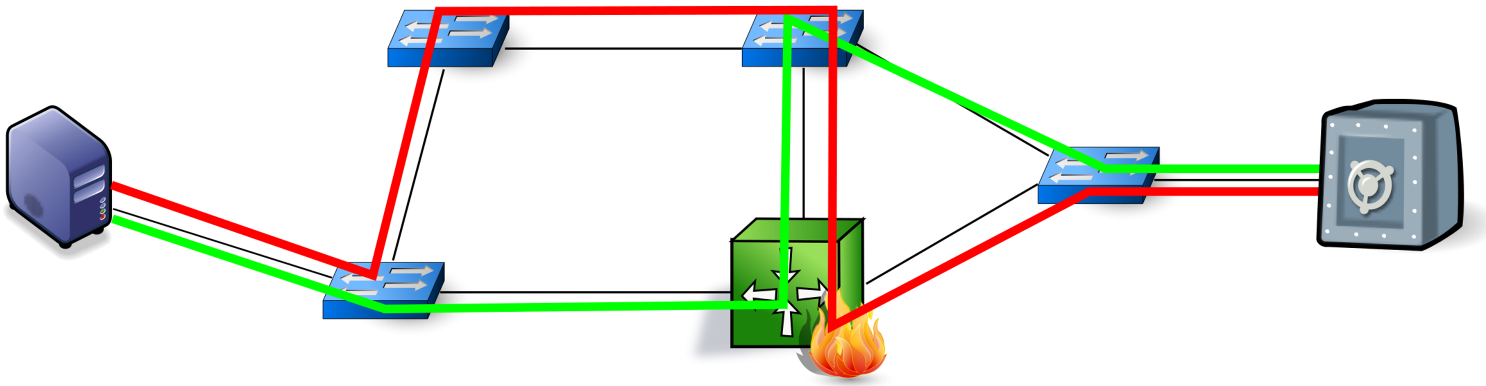


Example



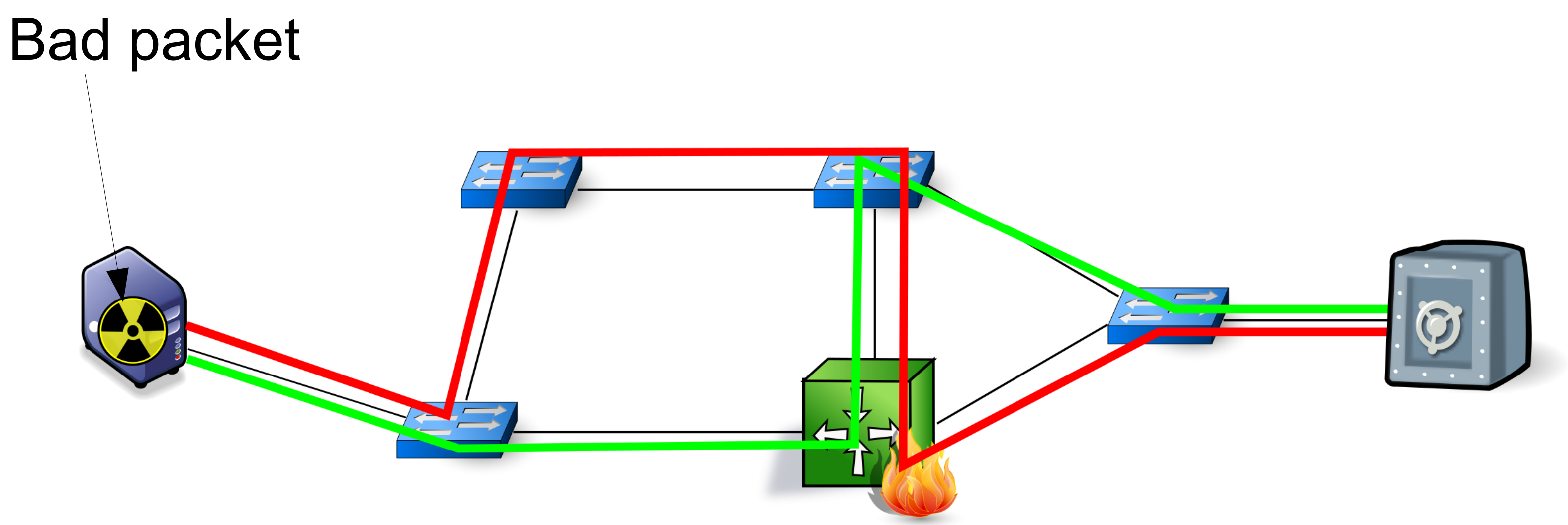
Waypoint Enforcement (WPE)

Example



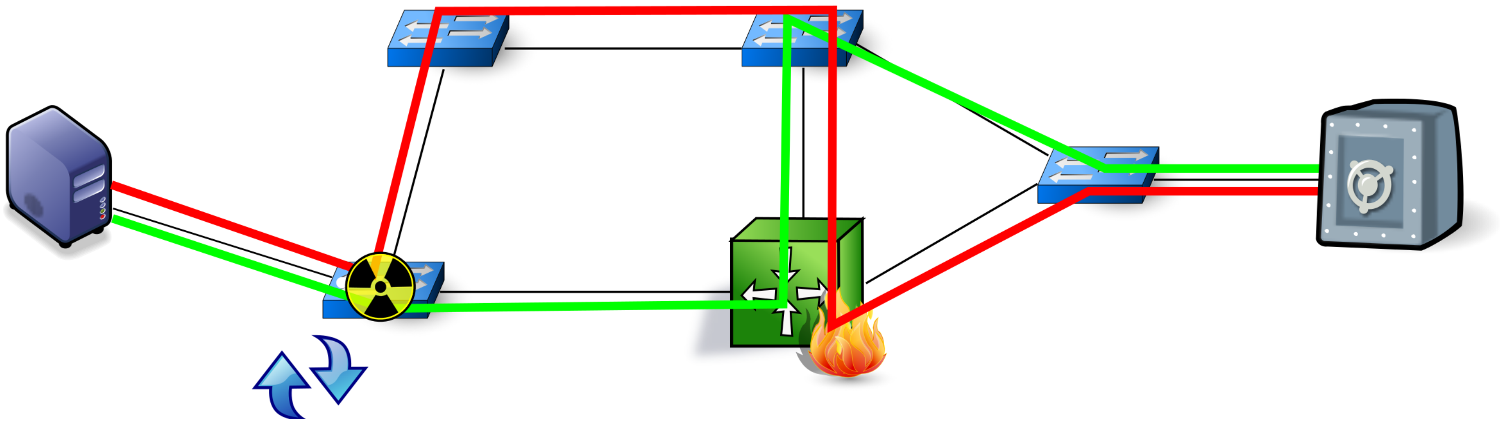
- Eventual consistency

Example



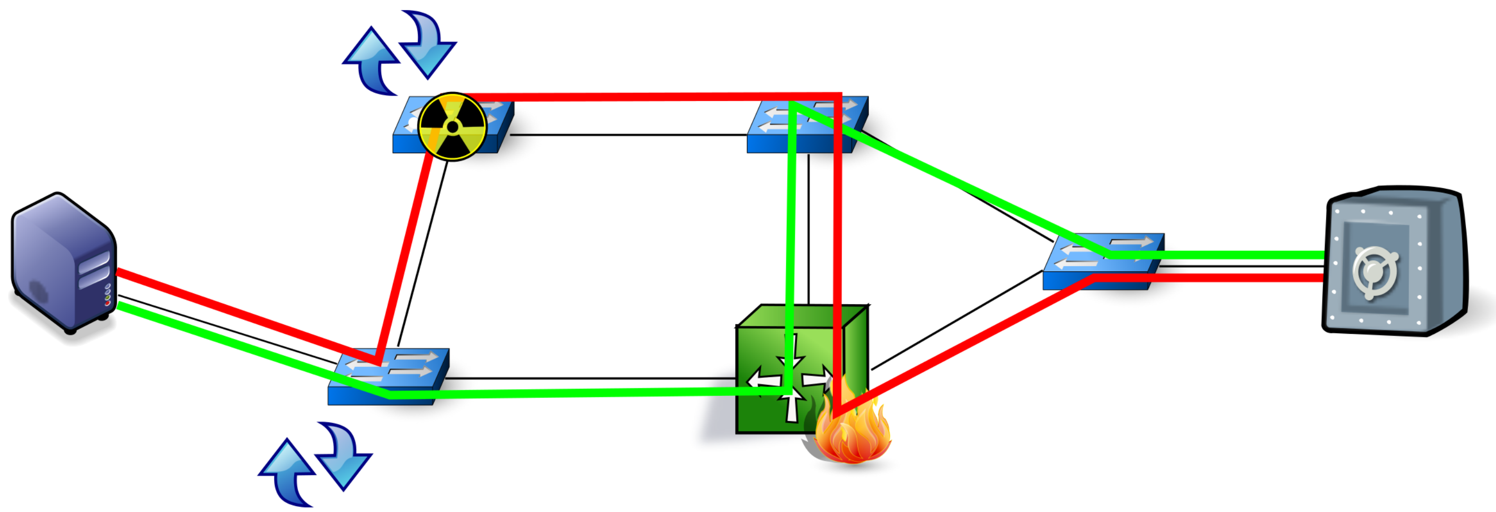
- ✔ Eventual consistency
- ➢ Transient consistency?

Example



- ✓ Eventual consistency
- ➢ Transient consistency?

Example



- ✓ Eventual consistency
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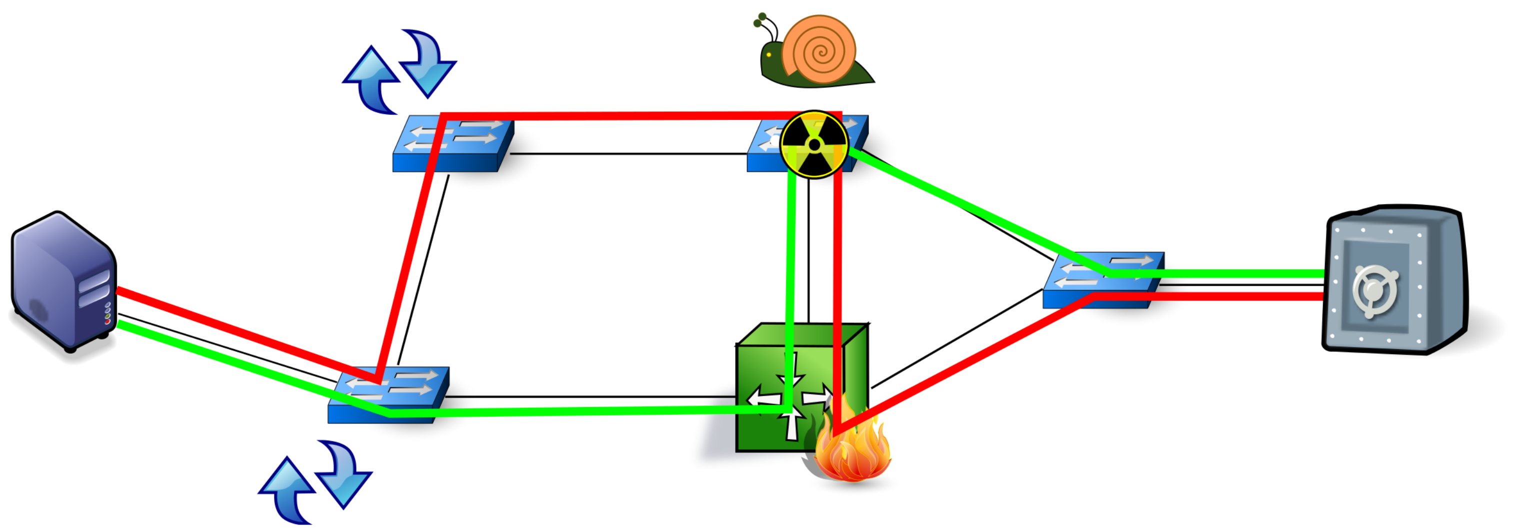
Example



- ✓ Eventual consistency
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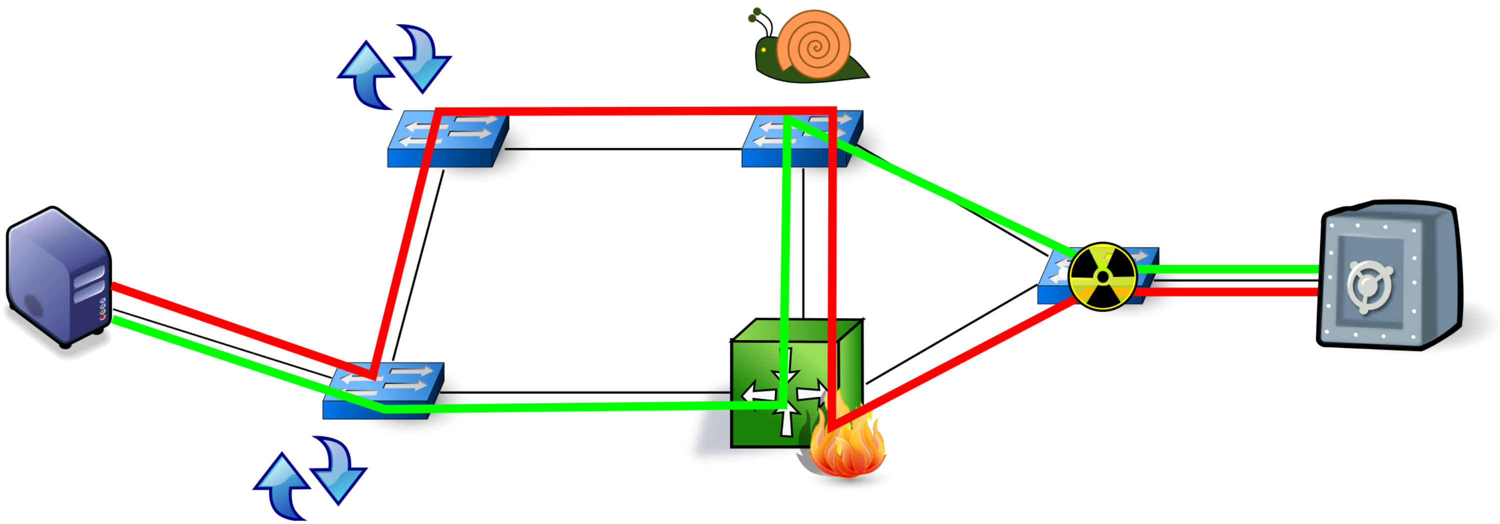
Example



- ✓ Eventual consistency
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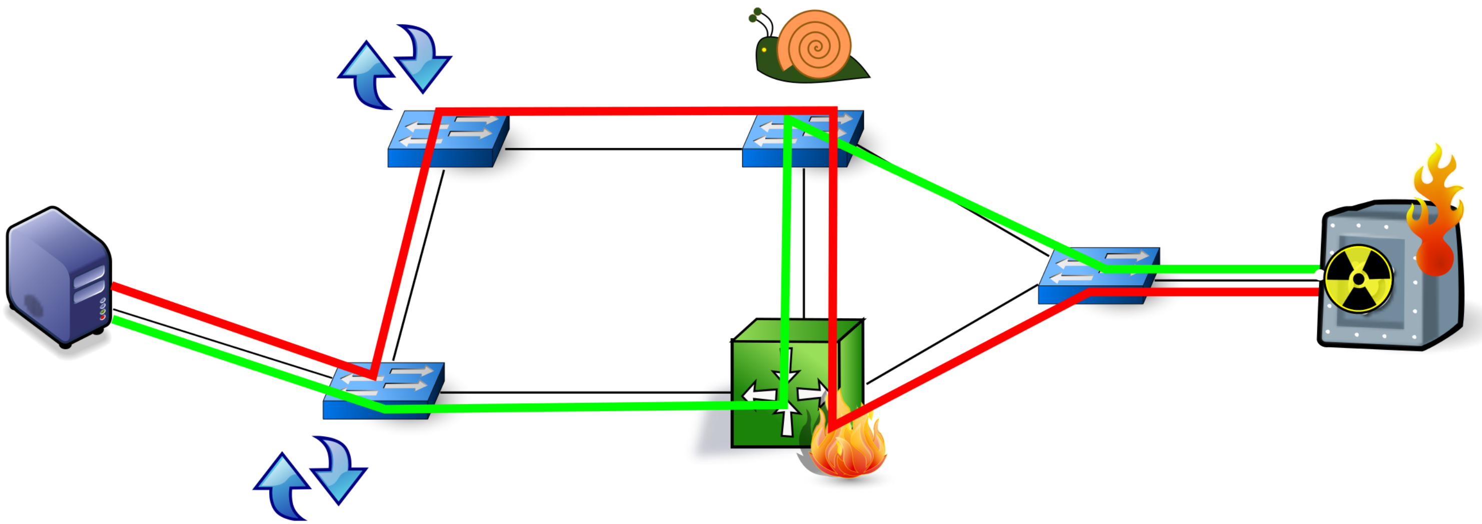
Example



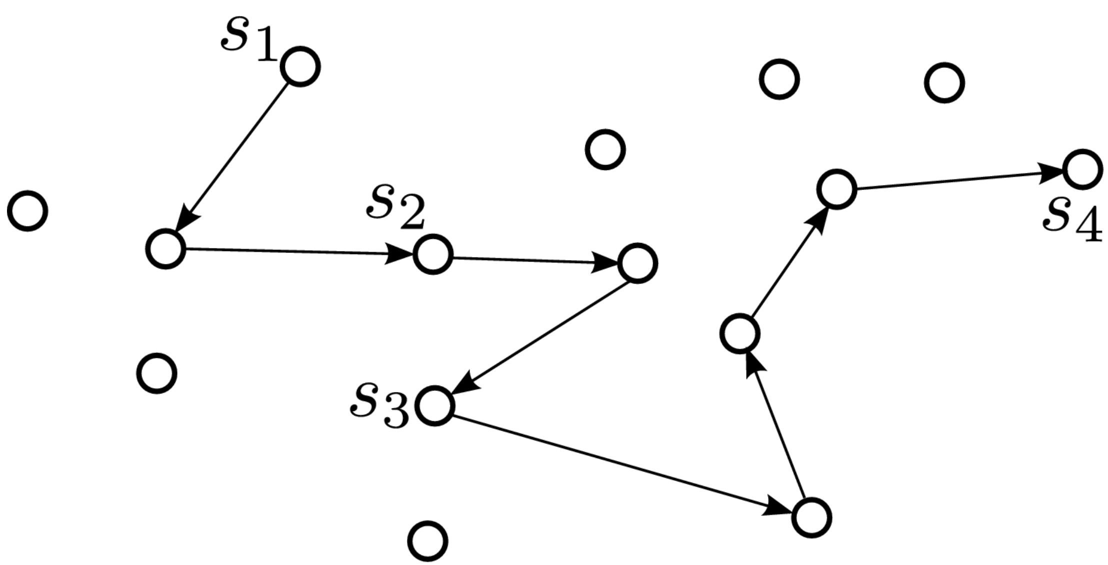
- ✔ Eventual consistency
- ✗ Transient consistency

Outline

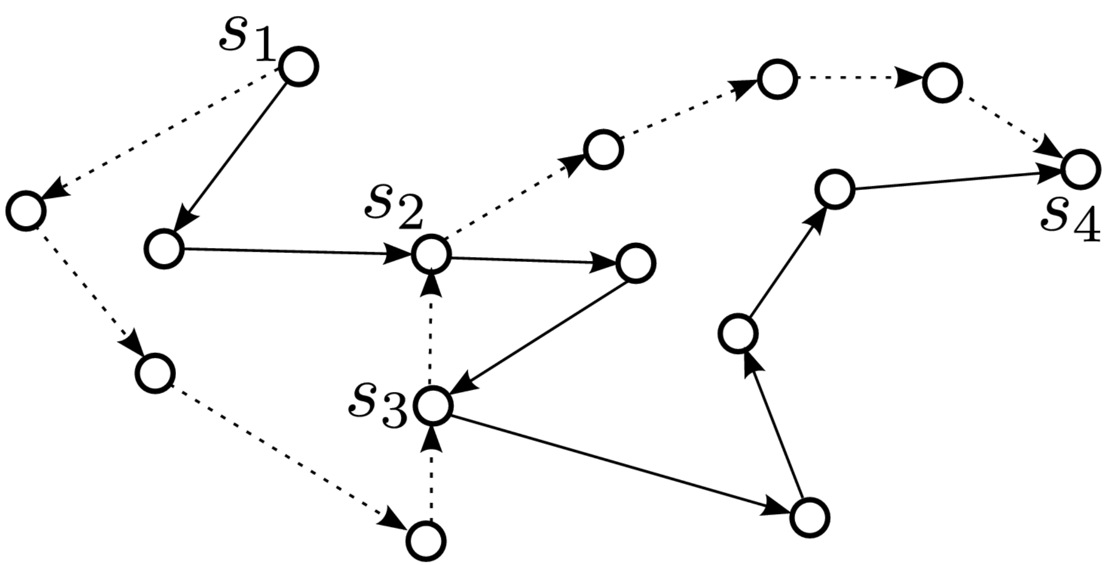
- What could possibly go wrong?
- It's not a trivial thing!
- But we present an optimal solution.

Model and a Trivial Compression

- Solid lines = current path



Model and a Trivial Compression



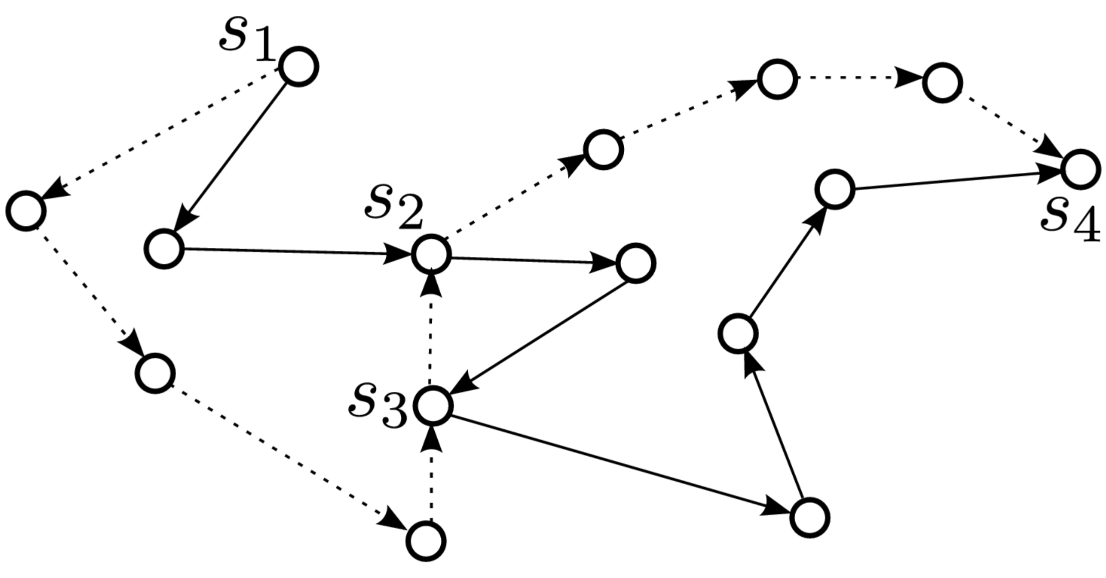
- Solid lines = current path
- Dashed lines = new path
- Flow-specific path

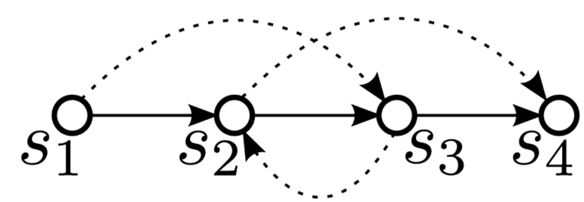
Model and a Trivial Compression

Solid lines = current path

Dashed lines = new path

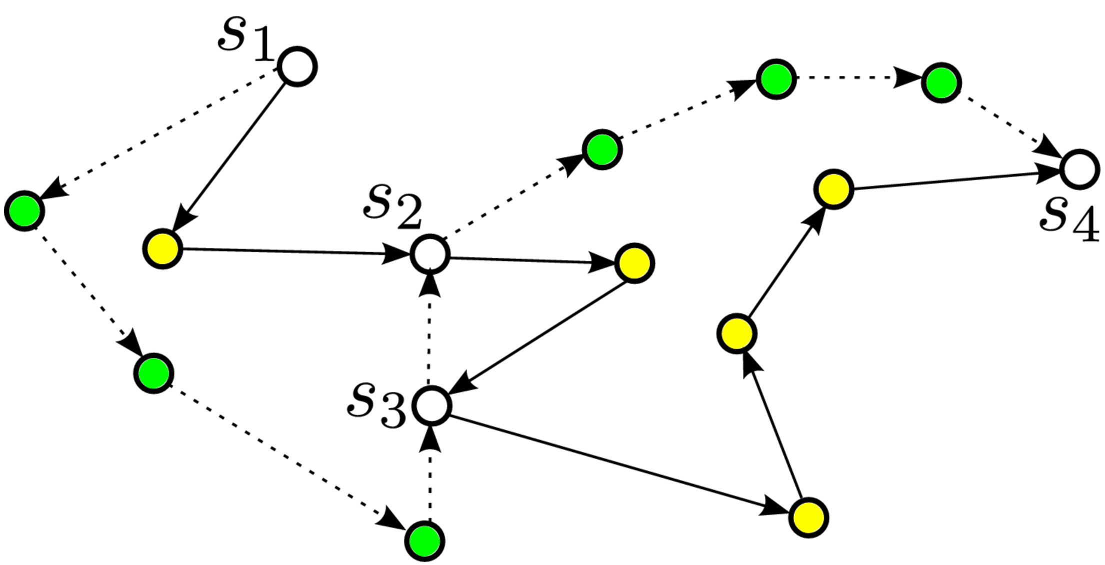
Flow-specific path

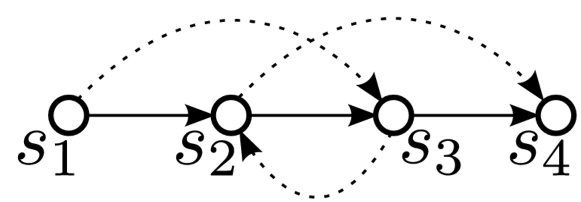




Model and a Trivial Compression

Solid lines = current path
Dashed lines = new path
Flow-specific path

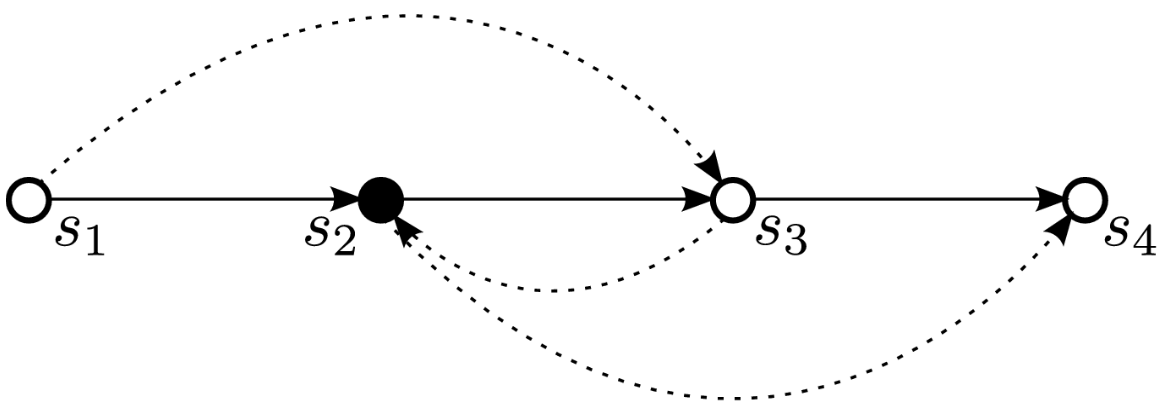




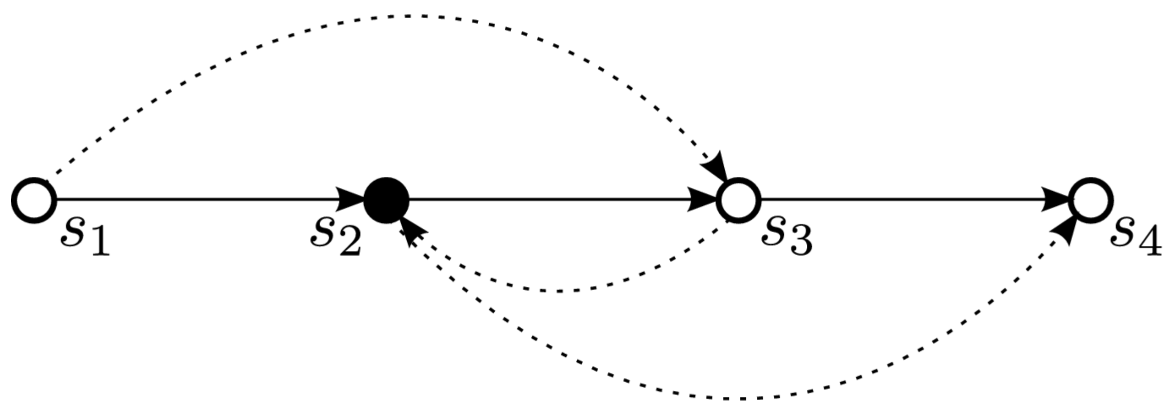
Safe to be updated
Safe to be left untouched

Consistency Properties

- WPE = every packet traverses the waypoint at least once
- LF = loop freedom



Update all “simultaneously“?



Update all “simultaneously“?

Not possible in practice!

What could possibly go wrong?

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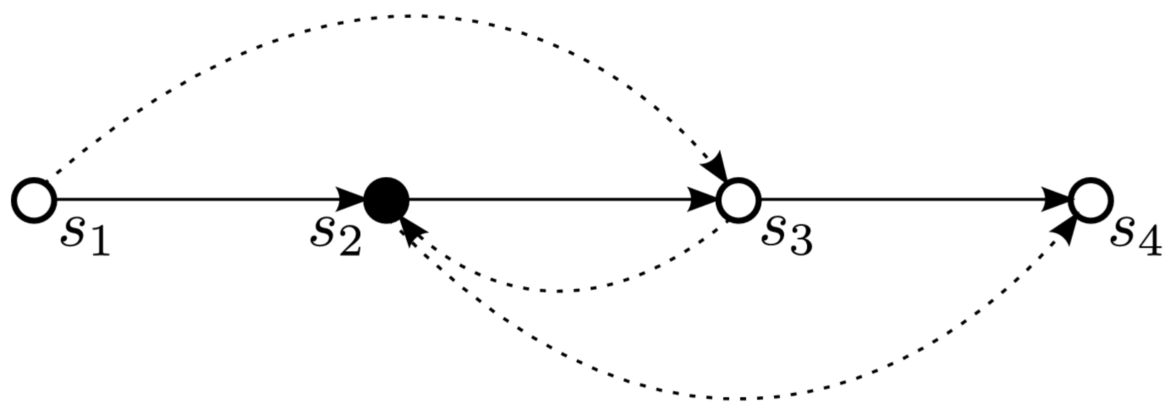
Not possible in practice!

What could possibly go wrong?

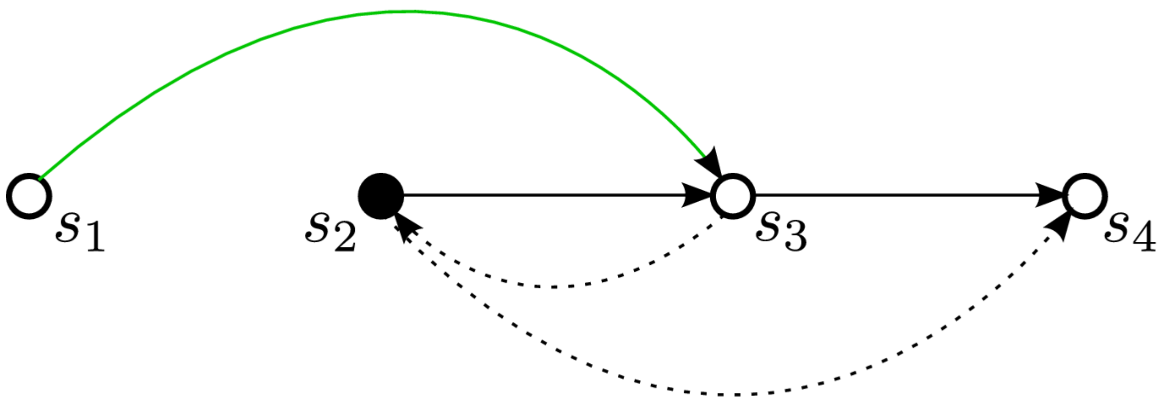
Update times can vary significantly (up to 10x higher than median [Dionysus – SIGCOMM'14])

Update all “simultaneously“?

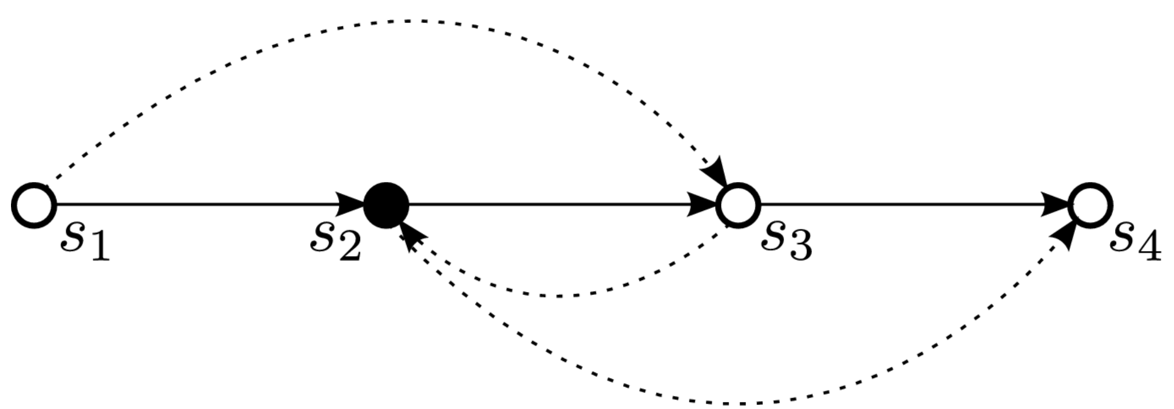


Update all “simultaneously“?

- Not waypoint enforced!

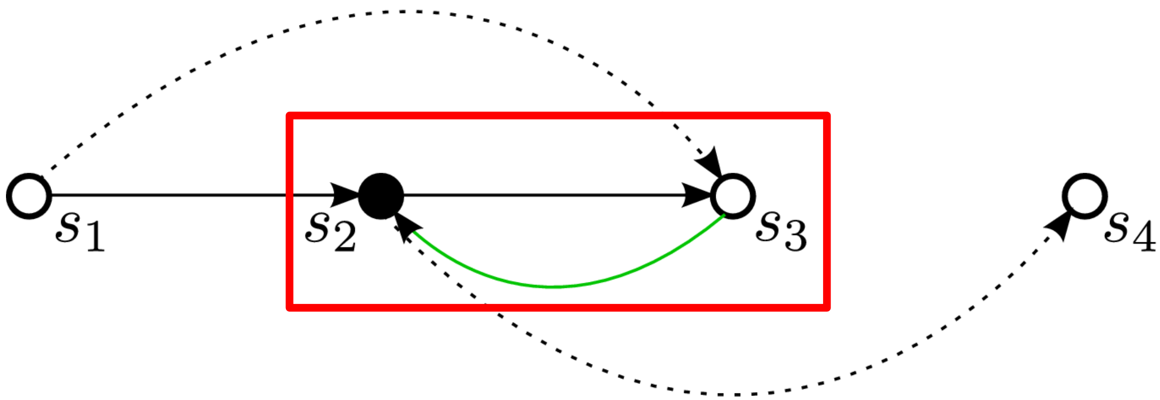


Delay s_1 ?

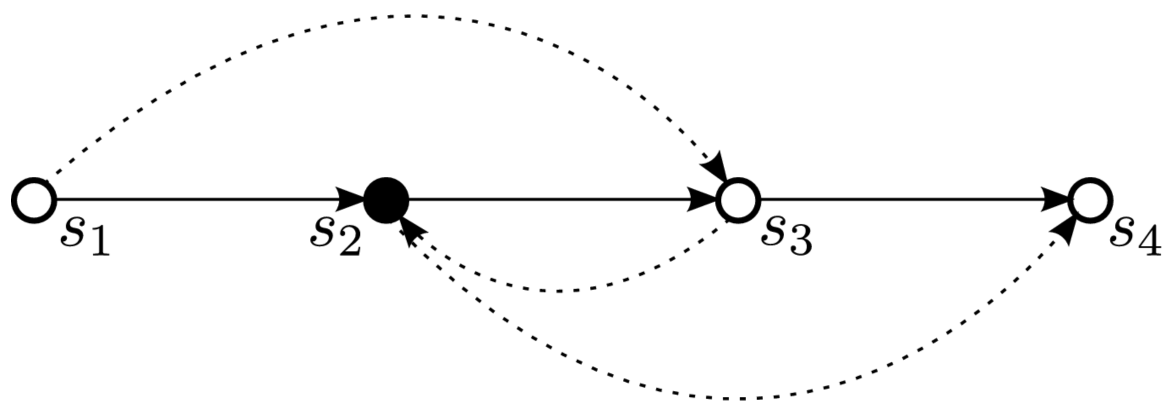


Delay s_1 ?

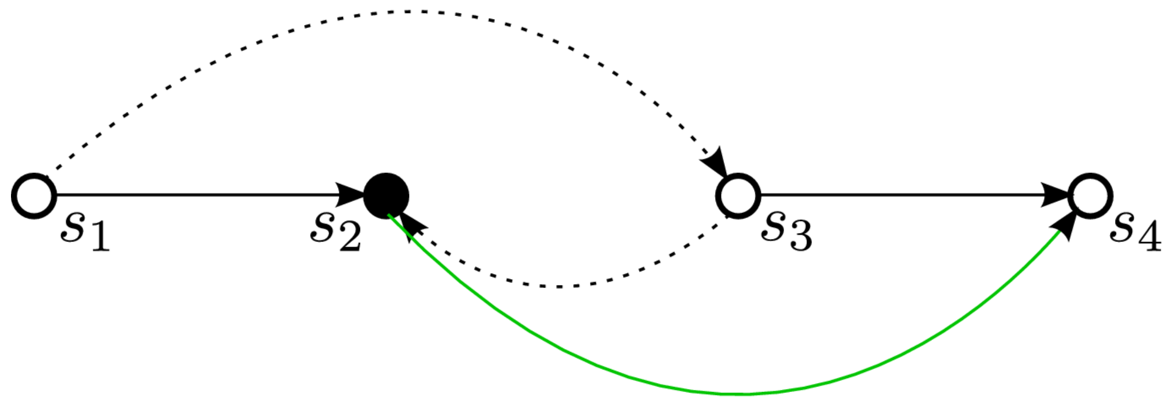
- Not loop free!



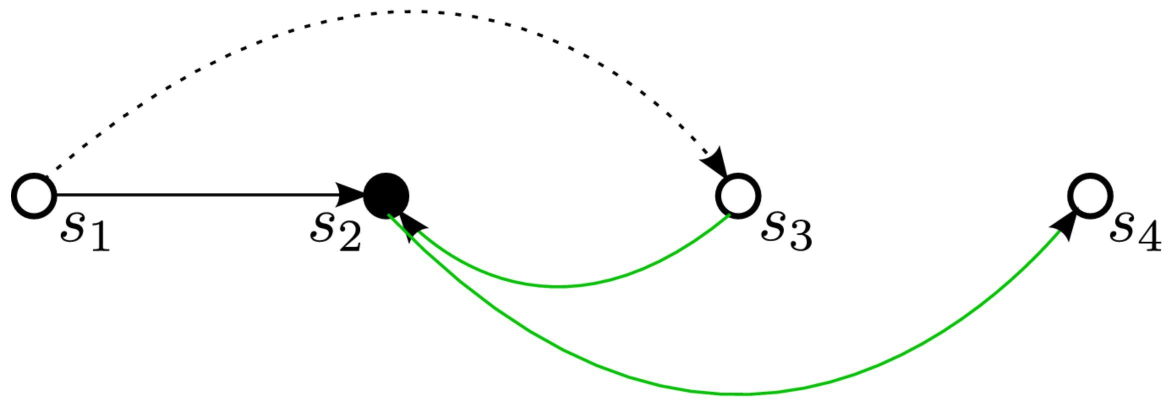
Update possible?



Update possible?

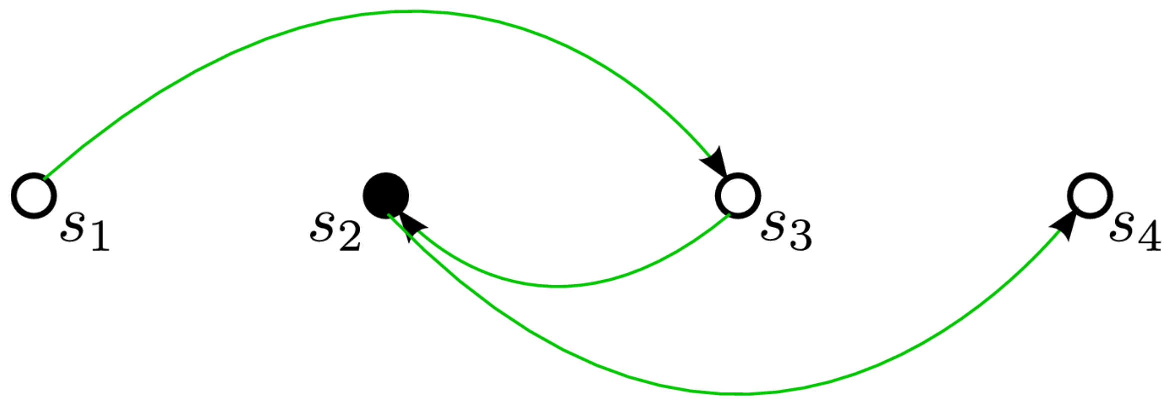


Update possible?



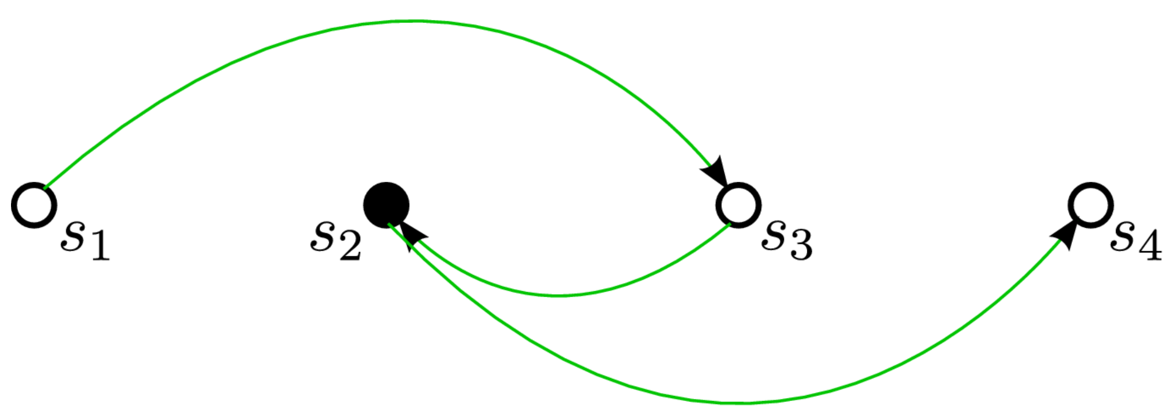
Update possible?

- Consistent transient states!



Rounds

- Round = set of parallel updates
- $R_1 = \{s_2\}, R_2 = \{s_3\}, R_3 = \{s_1\}$

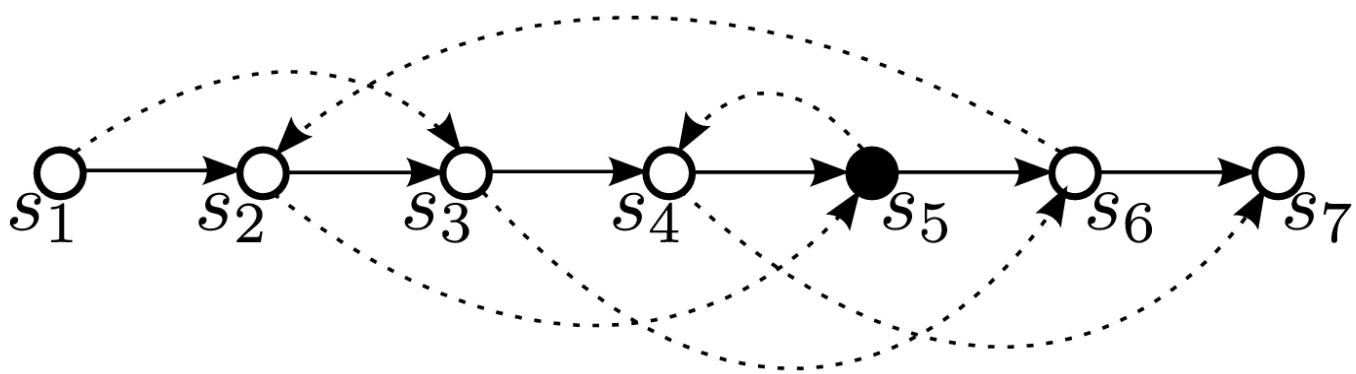


➔ Minimize number of rounds / communication overhead

Greedy Update Fails

- Greedy approach may:
  - take up to $\Omega(n)$ times more rounds
  - fail to find solution

See paper!



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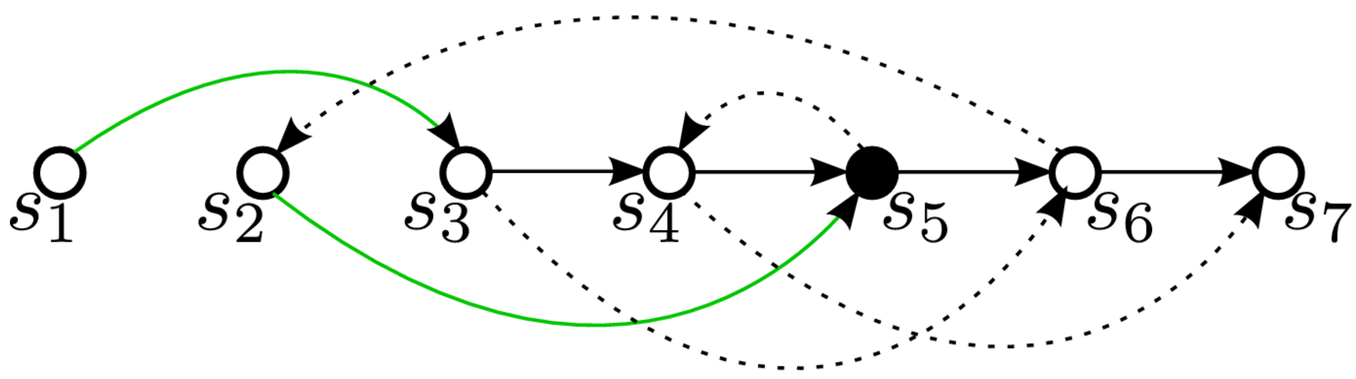
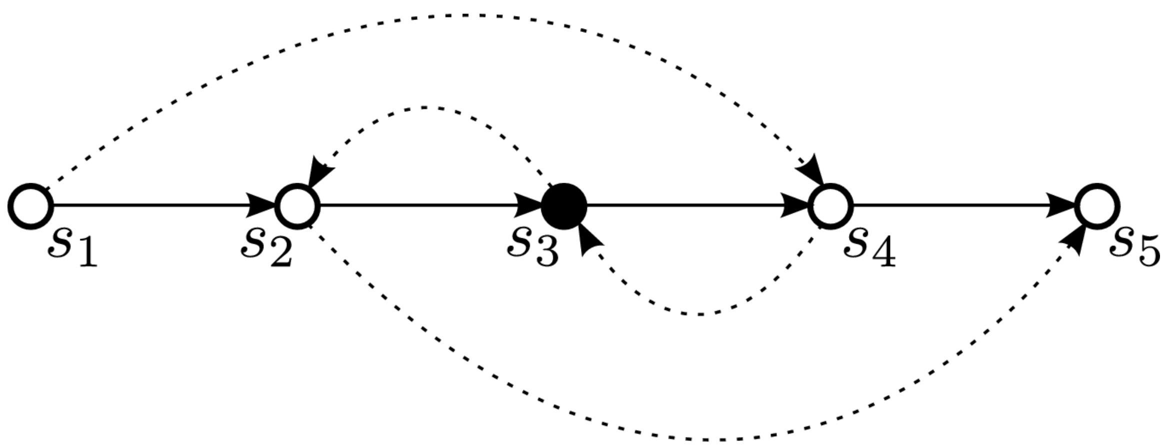


WPE - Update Algorithm

1. Switches < WP (new), > WP (old)



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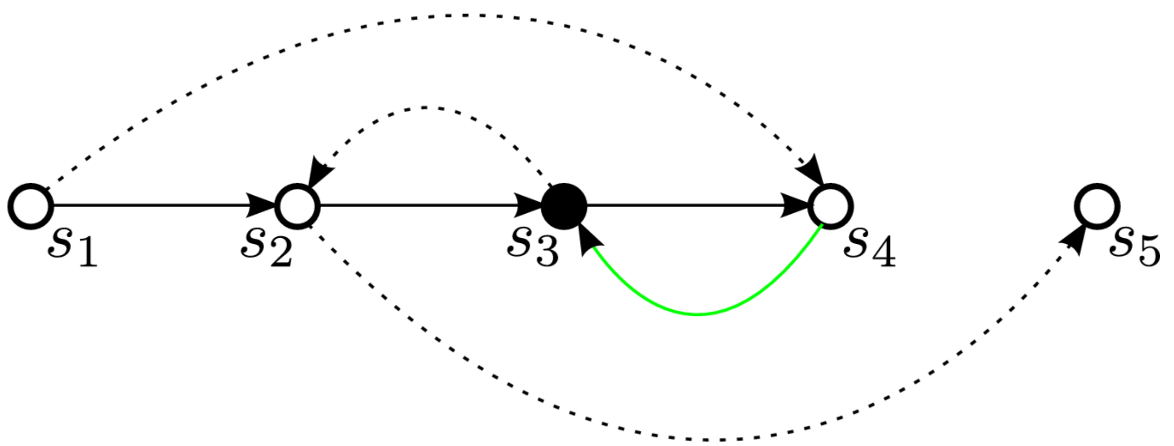

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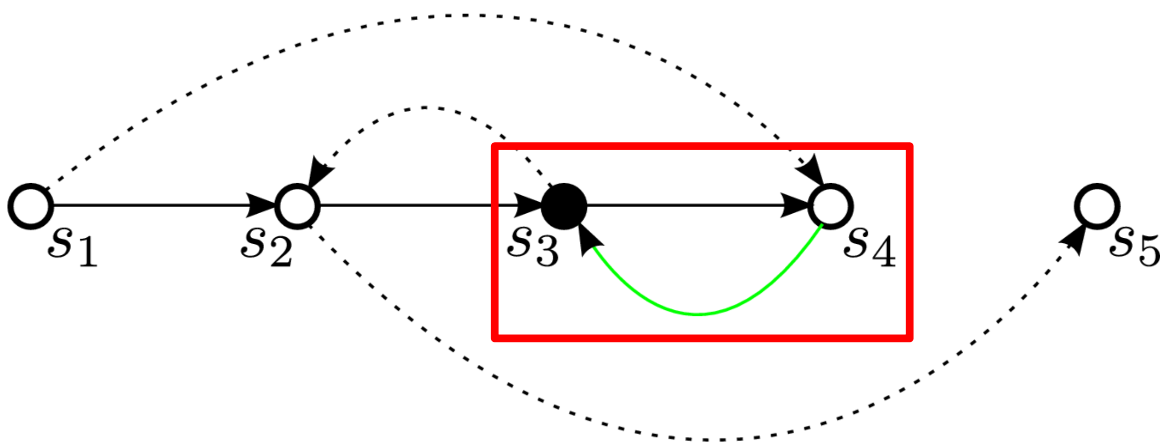

WPE - Update Algorithm

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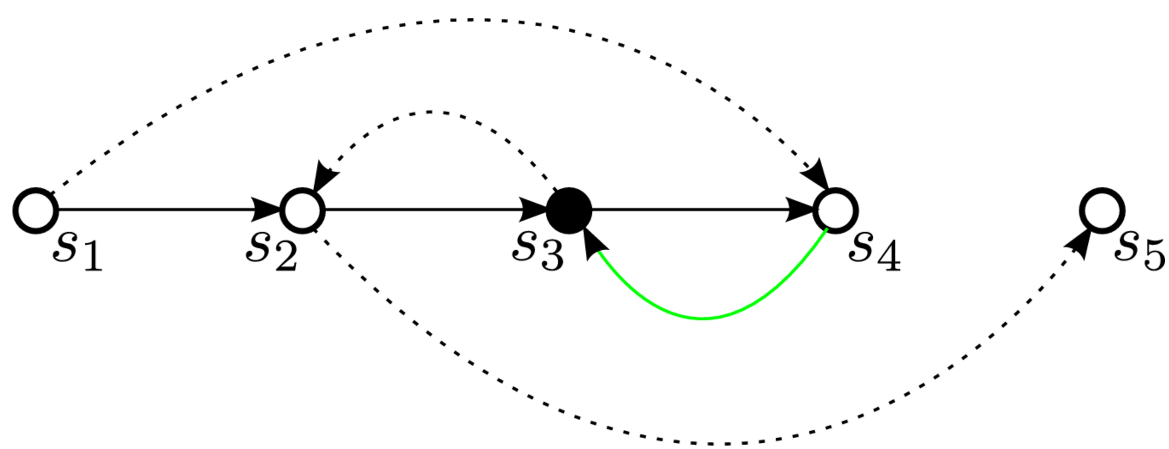

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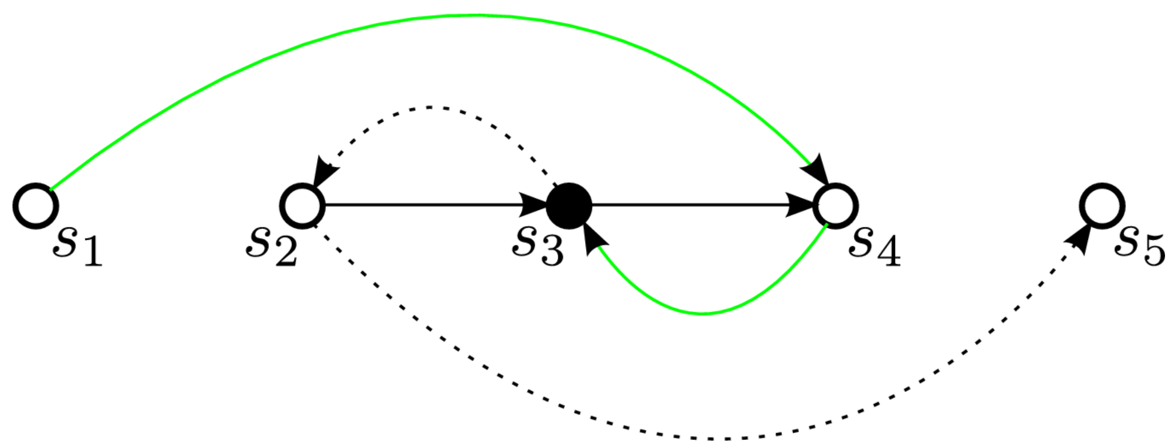
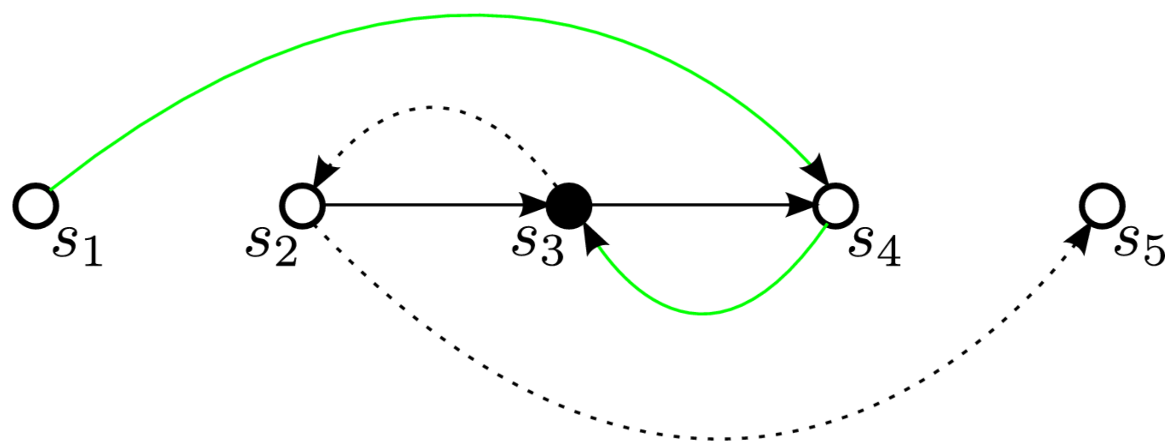


WPE - Update Algorithm

1. Switches < WP (new), > WP (old)
2. Switches < WP (new), < WP (old)
3. Remaining switches



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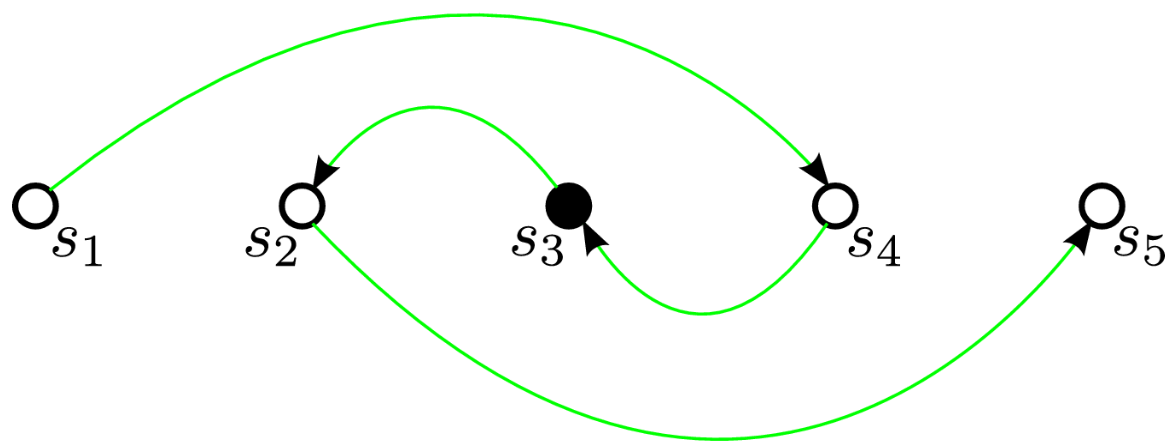
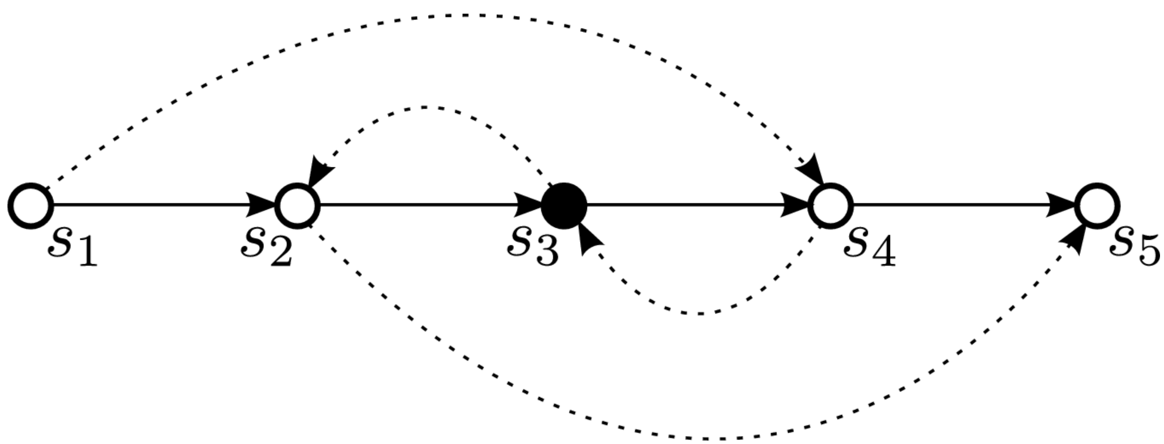


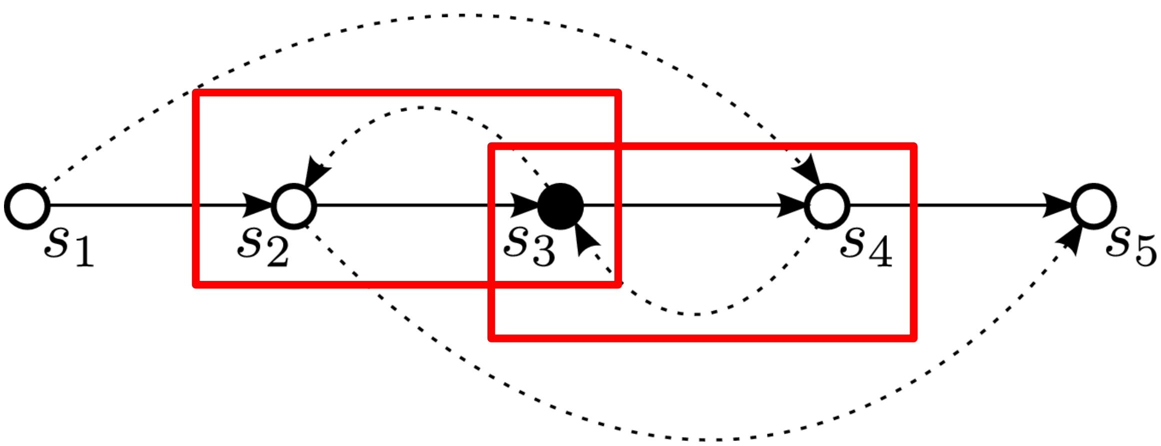
Constant in 3 rounds, but not LF!

LF and WPE Conflict



LF and WPE Conflict

- s_1, s_2 violate WPE; s_3, s_4 violate LF



Mixed Integer Program

Minimize Rounds

$$\min R \qquad \text{(Obj)}$$

$$
\begin{array}{rlr}
R \geq r \cdot x_v^r & r \in \mathcal{R}, v \in V & (1) \\
1 = \sum_{r \in \mathcal{R}} x_v^r & v \in V & (2) \\
y_{u,v}^r = 1 - \sum_{r' \leq r} x_u^r & r \in \mathcal{R}, (u,v) \in E_{\pi_1} & (3) \\
y_{u,v}^r = \sum_{r' \leq r} x_u^r & r \in \mathcal{R}, (u,v) \in E_{\pi_2} & (4) \\
a_s^r = 1 & r \in \mathcal{R} & (5) \\
a_v^r \geq a_u^r + y_{u,v}^{r-1} - 1 & r \in \mathcal{R}, (u,v) \in E & (6) \\
a_v^r \geq a_u^r + y_{u,v}^r - 1 & r \in \mathcal{R}, (u,v) \in E & (7) \\
y_{u,v}^{r-1 \vee r} \geq a_u^r + y_{u,v}^{r-1} - 1 & r \in \mathcal{R}, (u,v) \in E & (8) \\
y_{u,v}^{r-1 \vee r} \geq a_u^r + y_{u,v}^r - 1 & r \in \mathcal{R}, (u,v) \in E & (9)
\end{array}
$$

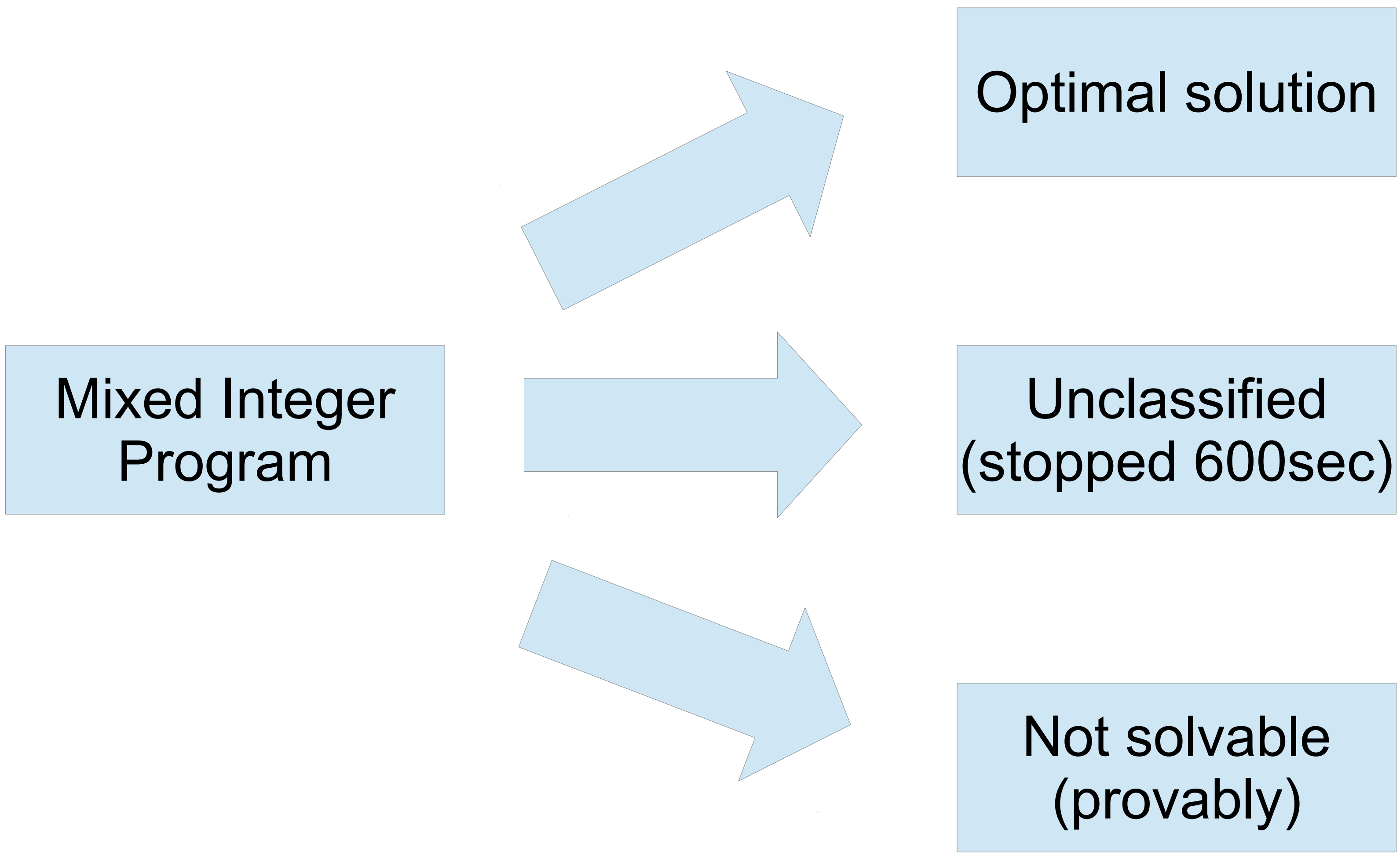
LF

$$
\begin{array}{rlr}
y_{u,v}^{r-1 \vee r} \leq \dfrac{l_v^r - l_u^r - 1}{|V| - 1} + 1 & r \in \mathcal{R}, (u,v) \in E & (10)
\end{array}
$$

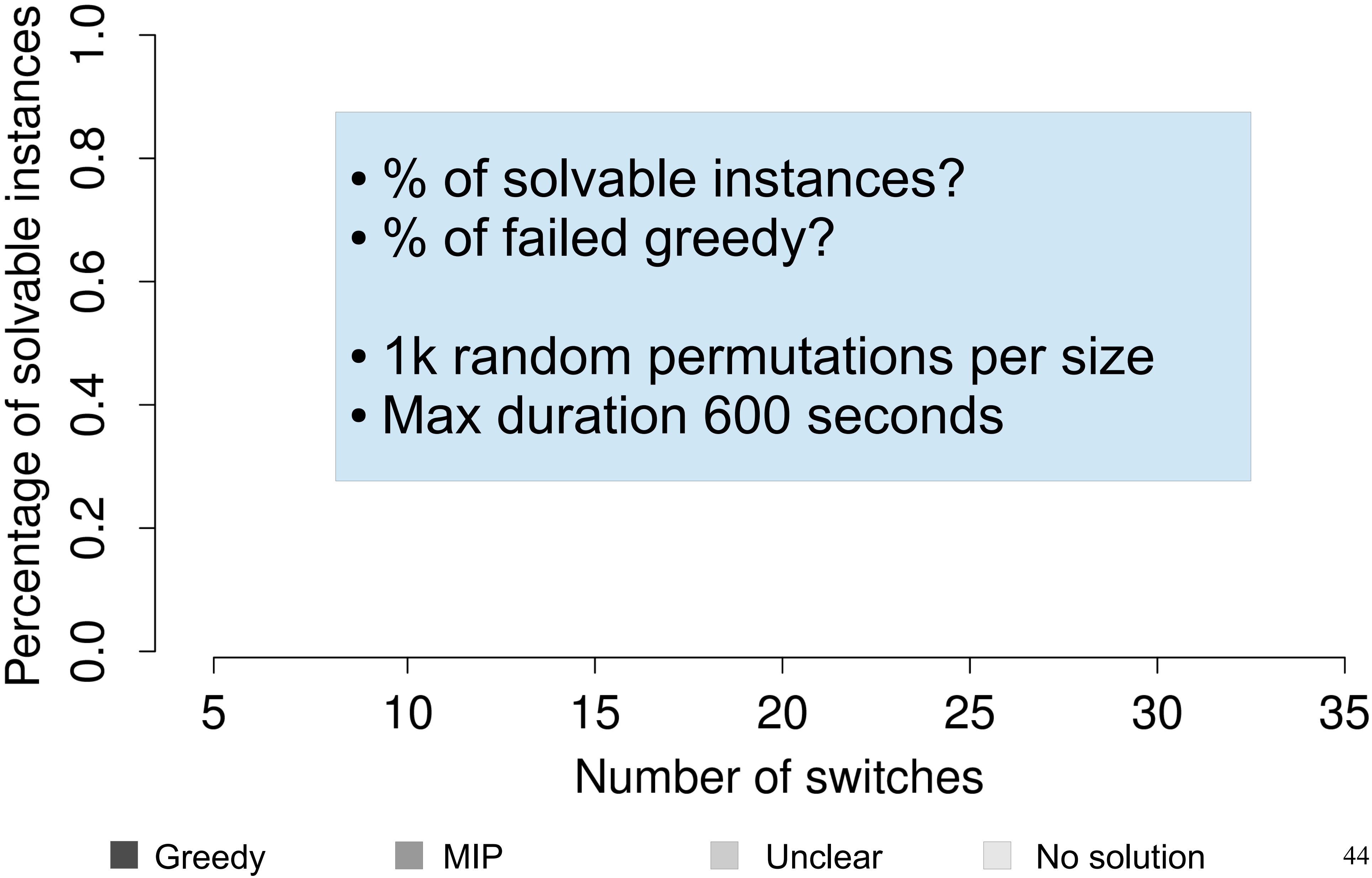
WPE

$$
\left\{
\begin{array}{rlr}
\overline{a}_s^r = 1 & r \in \mathcal{R} & (11) \\
\overline{a}_v^r \geq \overline{a}_u^r + y_{u,v}^{r-1} - 1 & r \in \mathcal{R}, (u,v) \in E_{\overline{\mathsf{WP}}} & (12) \\
\overline{a}_v^r \geq \overline{a}_u^r + y_{u,v}^r - 1 & r \in \mathcal{R}, (u,v) \in E_{\overline{\mathsf{WP}}} & (13) \\
\overline{a}_t^r = 0 & r \in \mathcal{R} & (14)
\end{array}
\right.
$$

Mixed Integer Program



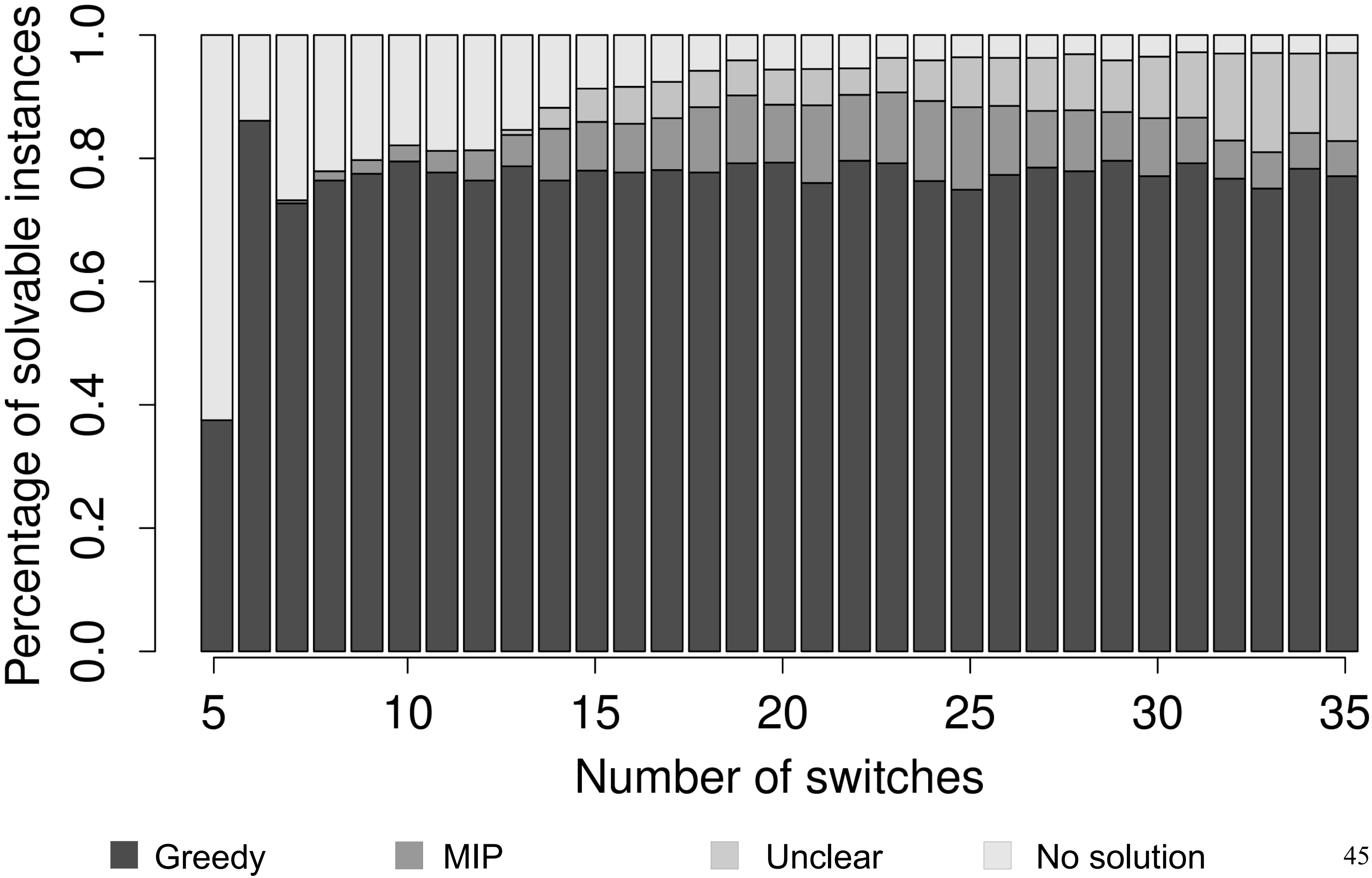
Solvability Analysis



- % of solvable instances?
- % of failed greedy?

- 1k random permutations per size
- Max duration 600 seconds

Solvability Analysis



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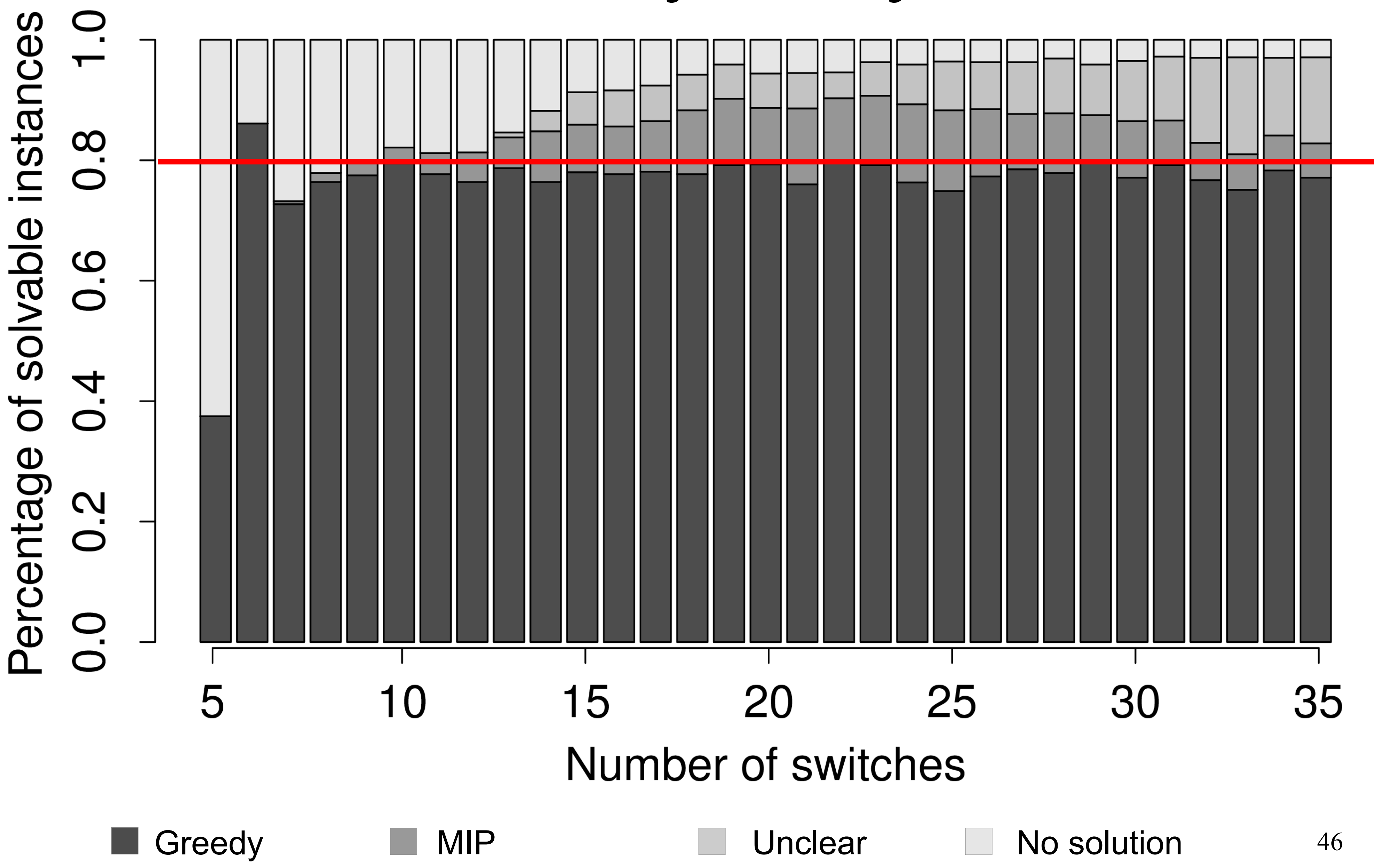

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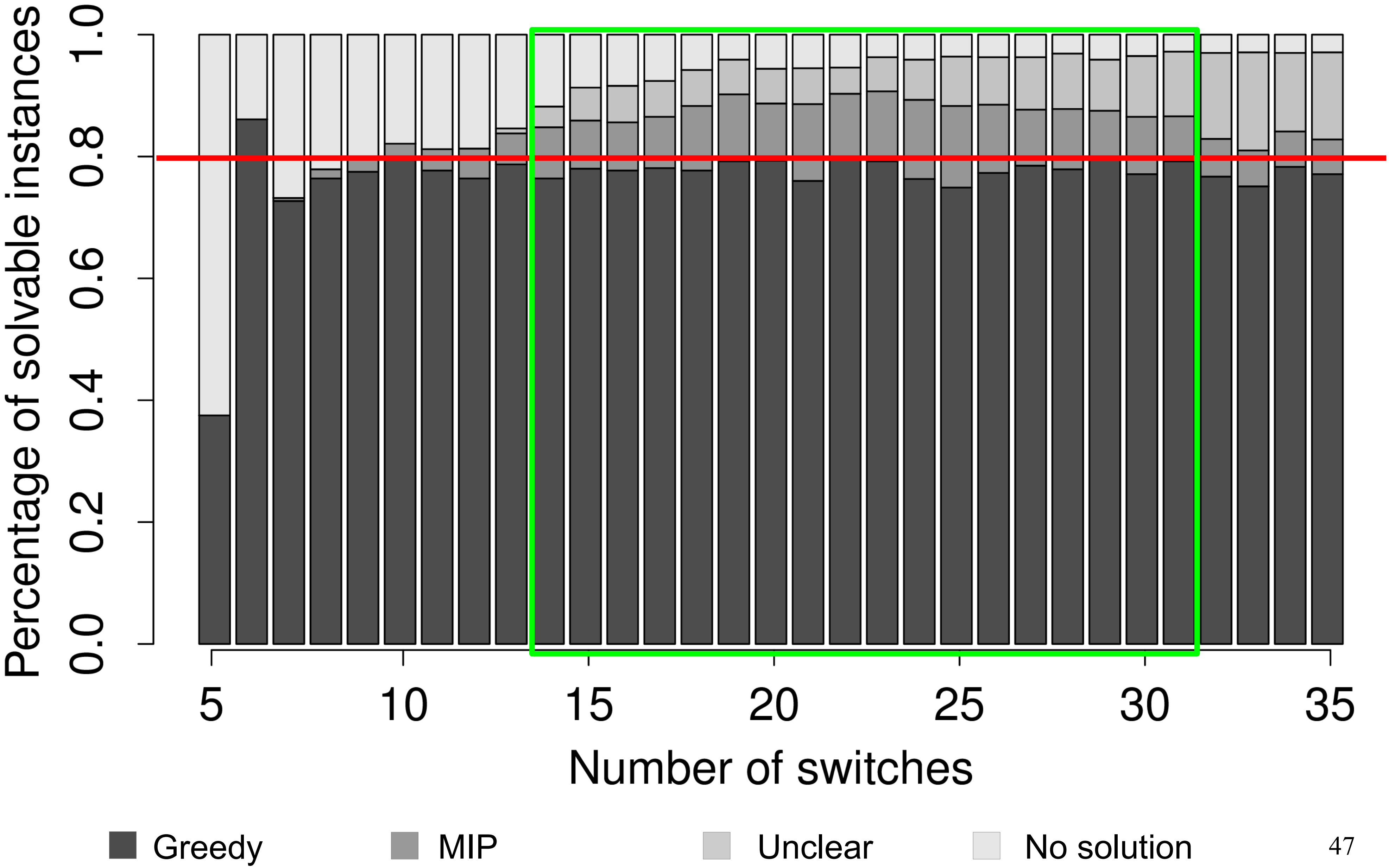


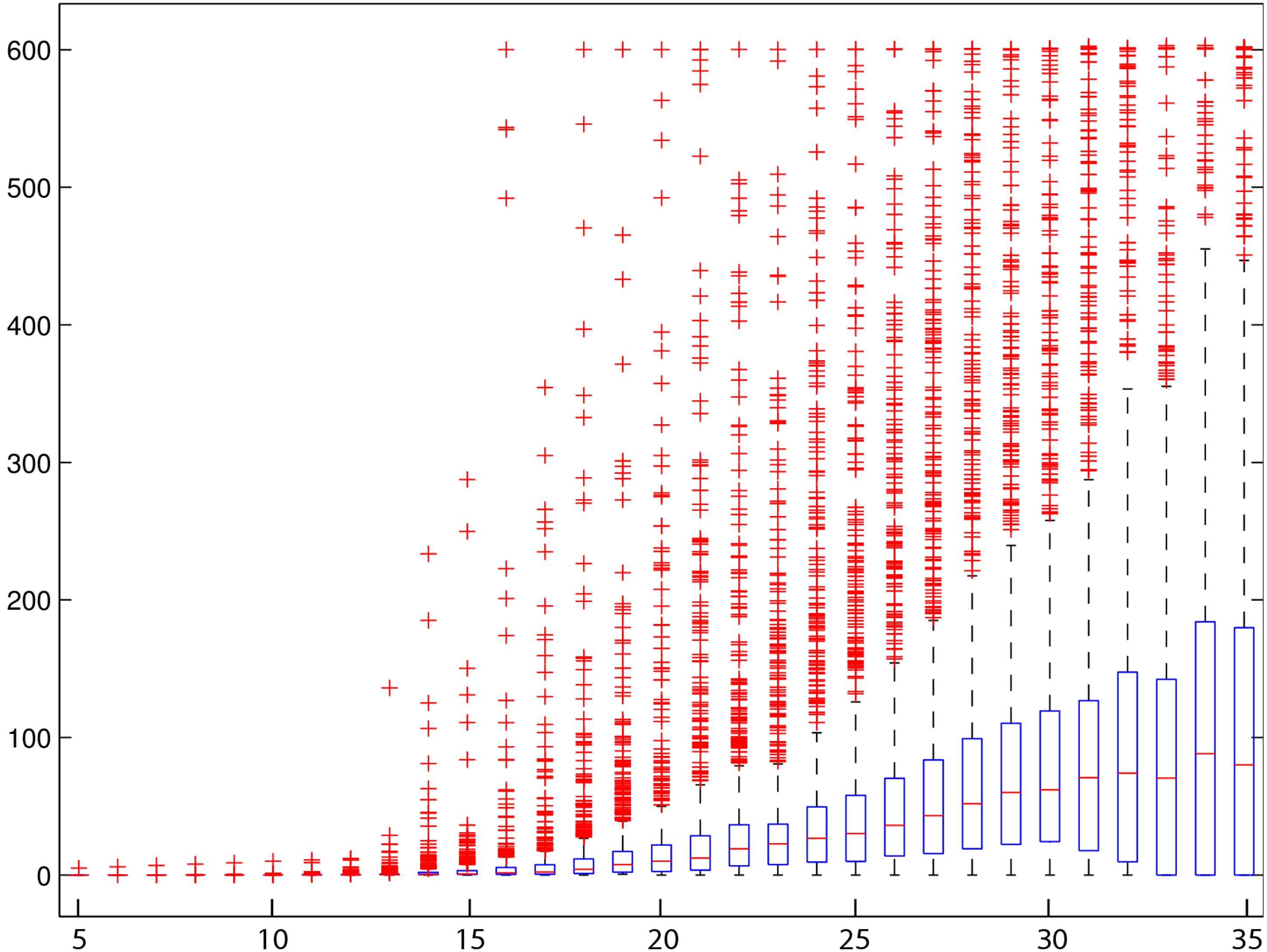
Conclusion

- Transient consistency is not easy to guarantee
- LF and WPE might even conflict
- Greedy can fail to find consistent updates

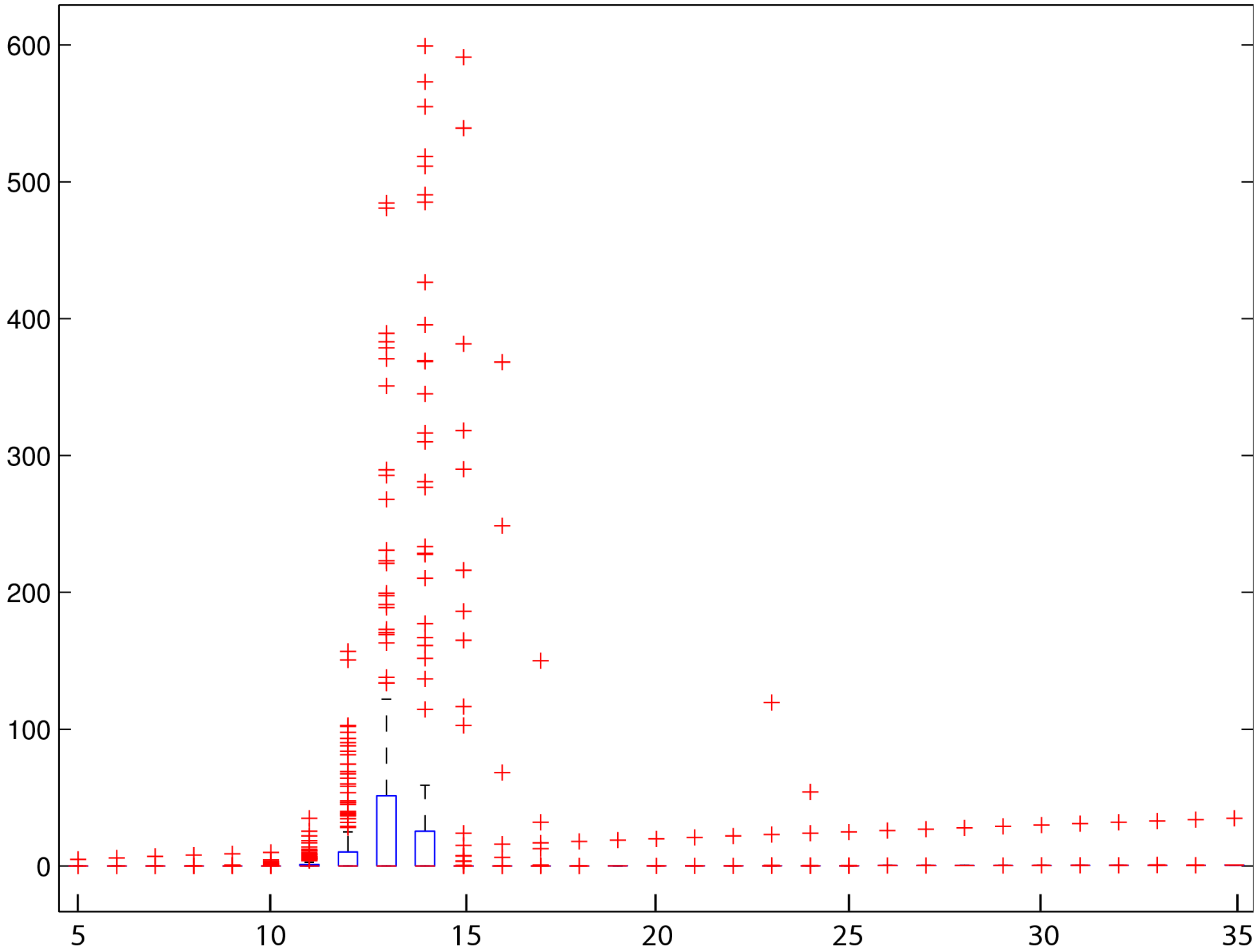
Dynamic WPE + LF updates are hard to find!

Backup Slides

Scaling of MIP – Solvable Instances



Scaling of MIP – Unsolvable Inst.



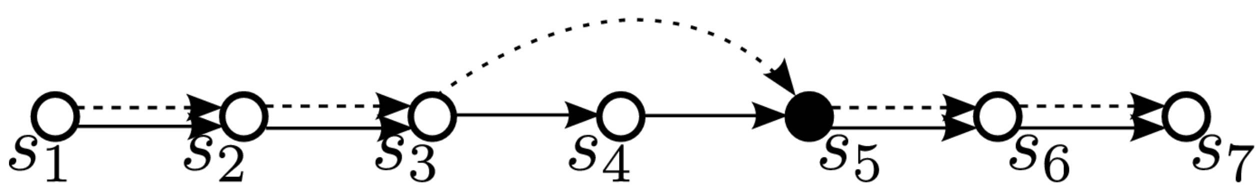
SDN: Tagging vs. Dynamic

Tagging

- Per packet consistency
  → Included security

Dynamic

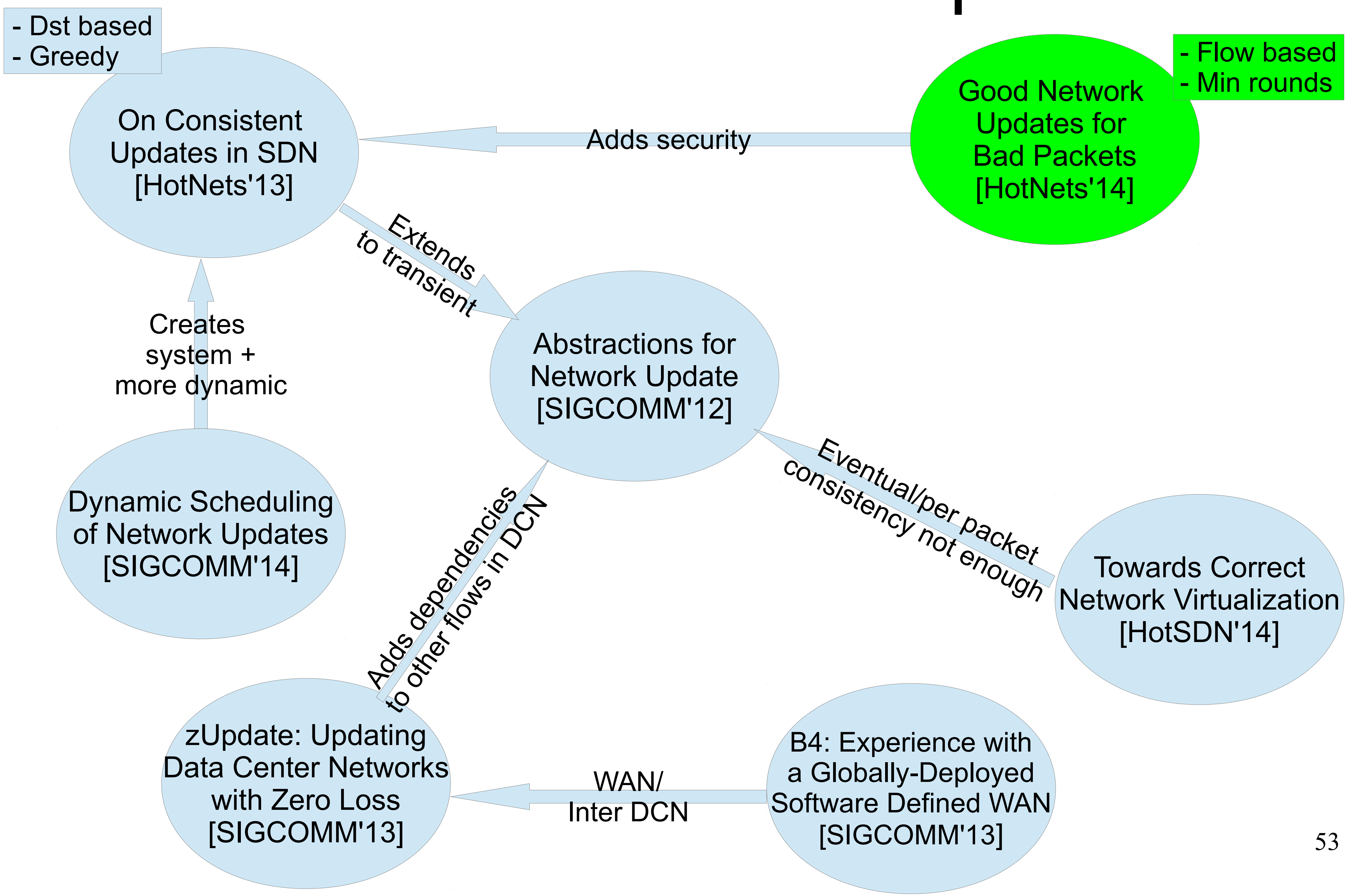
- Load adaptive [Dionysus]
- Parts updated earlier
- Efficient partial updates



Partial update:

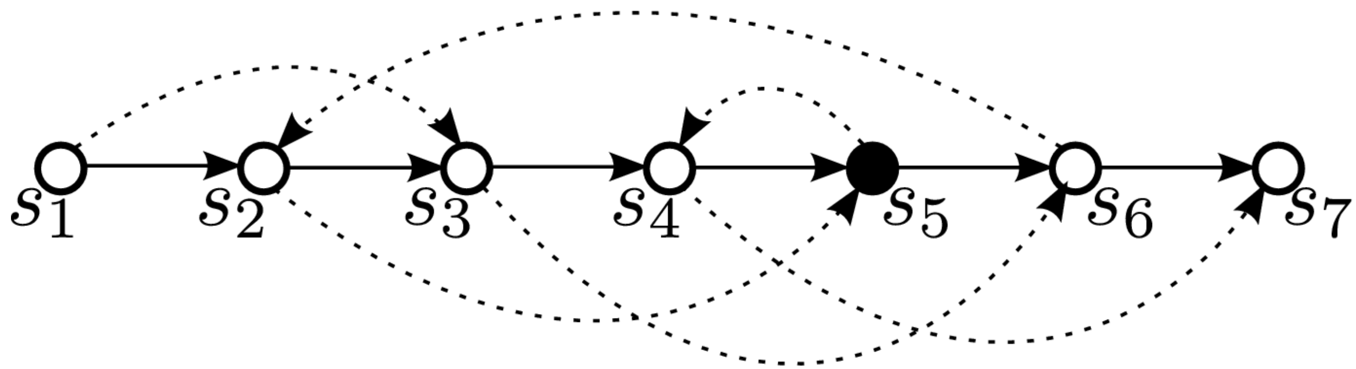
- Tagging: communication with all switches
- Dynamic: communication only with affected switches

SDN – Mind Map



- Dst based
- Greedy
On Consistent Updates in SDN [HotNets'13]
Adds security
Good Network Updates for Bad Packets [HotNets'14]
- Flow based
- Min rounds
Extends to transient
Creates system + more dynamic
Abstractions for Network Update [SIGCOMM'12]
Dynamic Scheduling of Network Updates [SIGCOMM'14]
Eventual/per packet consistency not enough
Towards Correct Network Virtualization [HotSDN'14]
Adds dependencies to other flows in DCN
zUpdate: Updating Data Center Networks with Zero Loss [SIGCOMM'13]
WAN/ Inter DCN
B4: Experience with a Globally-Deployed Software Defined WAN [SIGCOMM'13]

Solution for Greedy Fail



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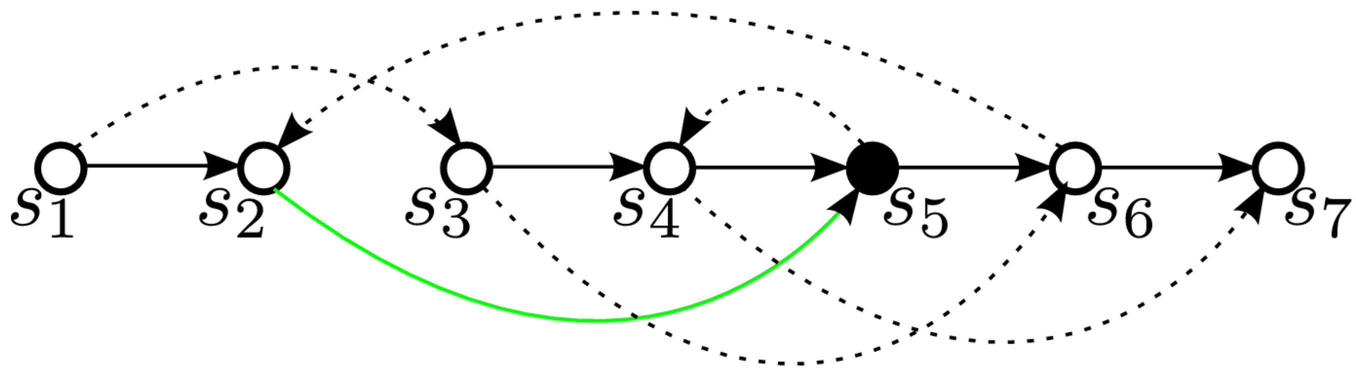

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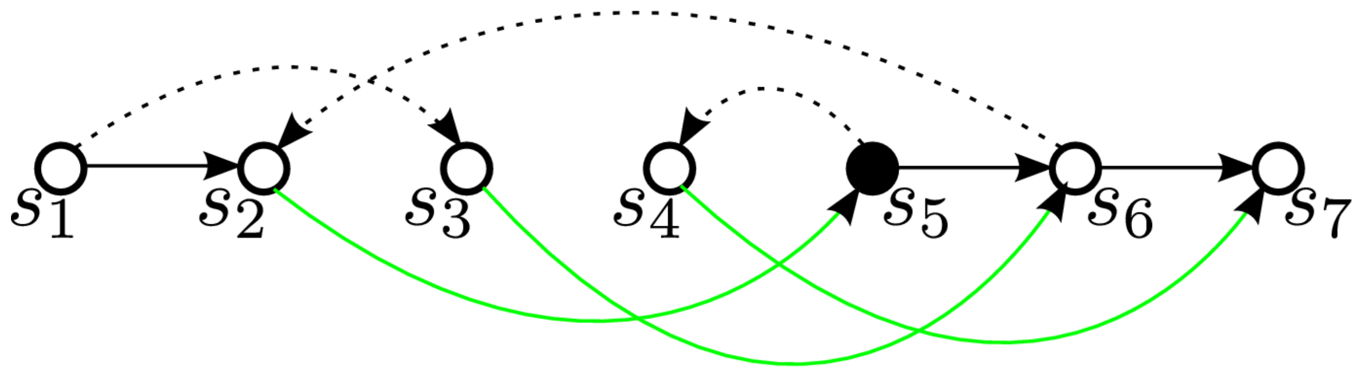

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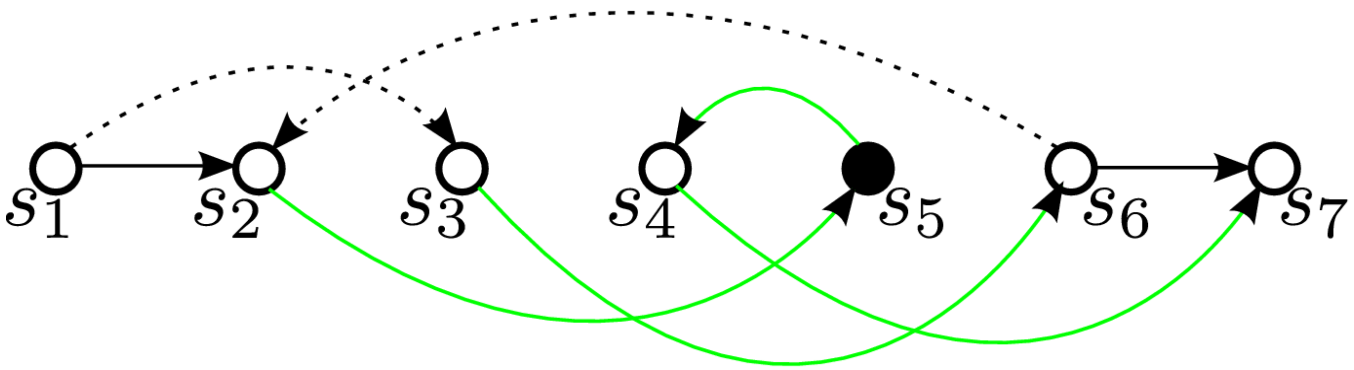

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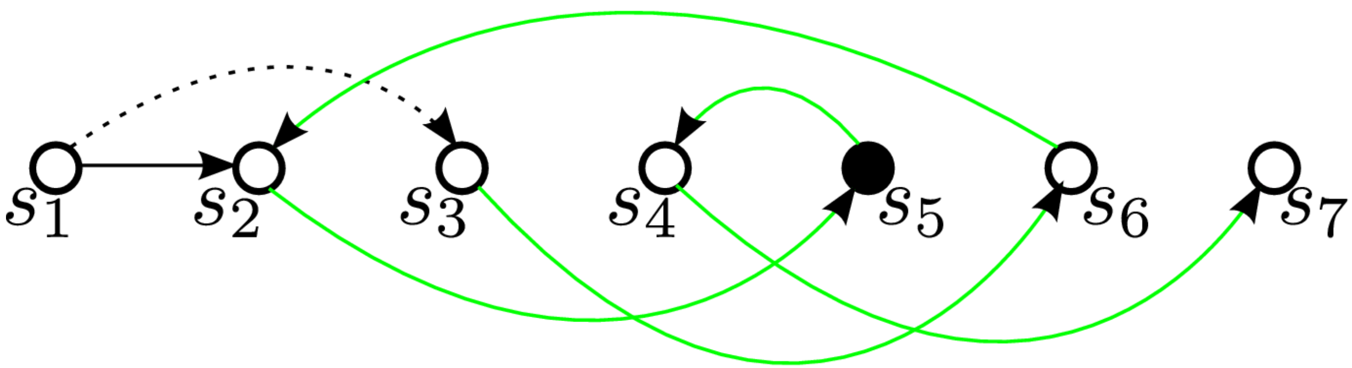

Solution for Greedy Fail