Management of Time Requirements in Component-based Systems

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Component-based Software Engineering

Business Goals & System Requirements

Component-based Software Engineering

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Component-based Software Engineering

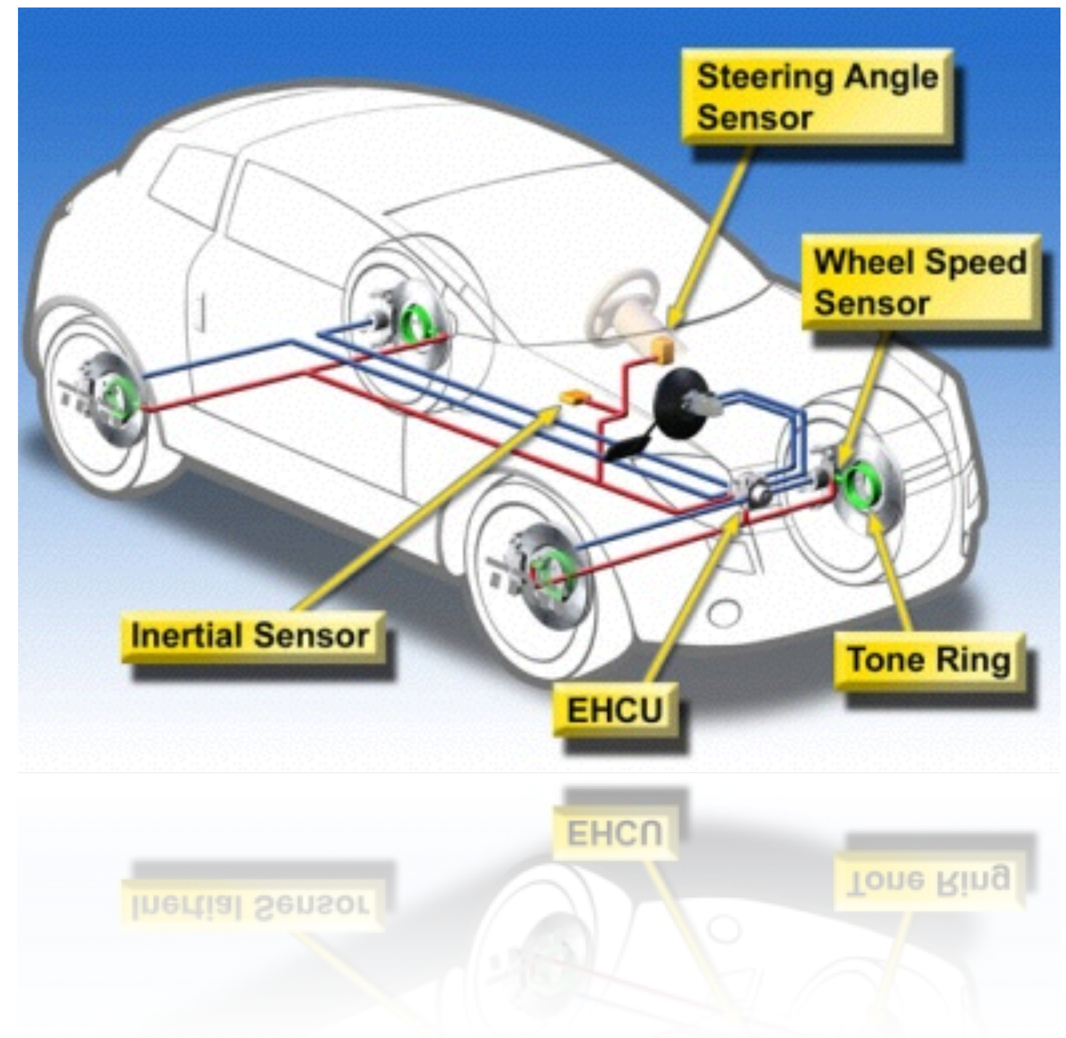
modularity, reusability, separation of concerns

Timing Requirements

Timing Requirements

Vehicle Control Systems

- *Electronic Stability Control (ESC)*
- *Anti-lock braking system (ABS)*



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Smart Phones

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- *Sensors - motion tracking*

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Web Service Compositions

- *Ticket Booking*
- *Stock Quotes*

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Existing Approach: LTR

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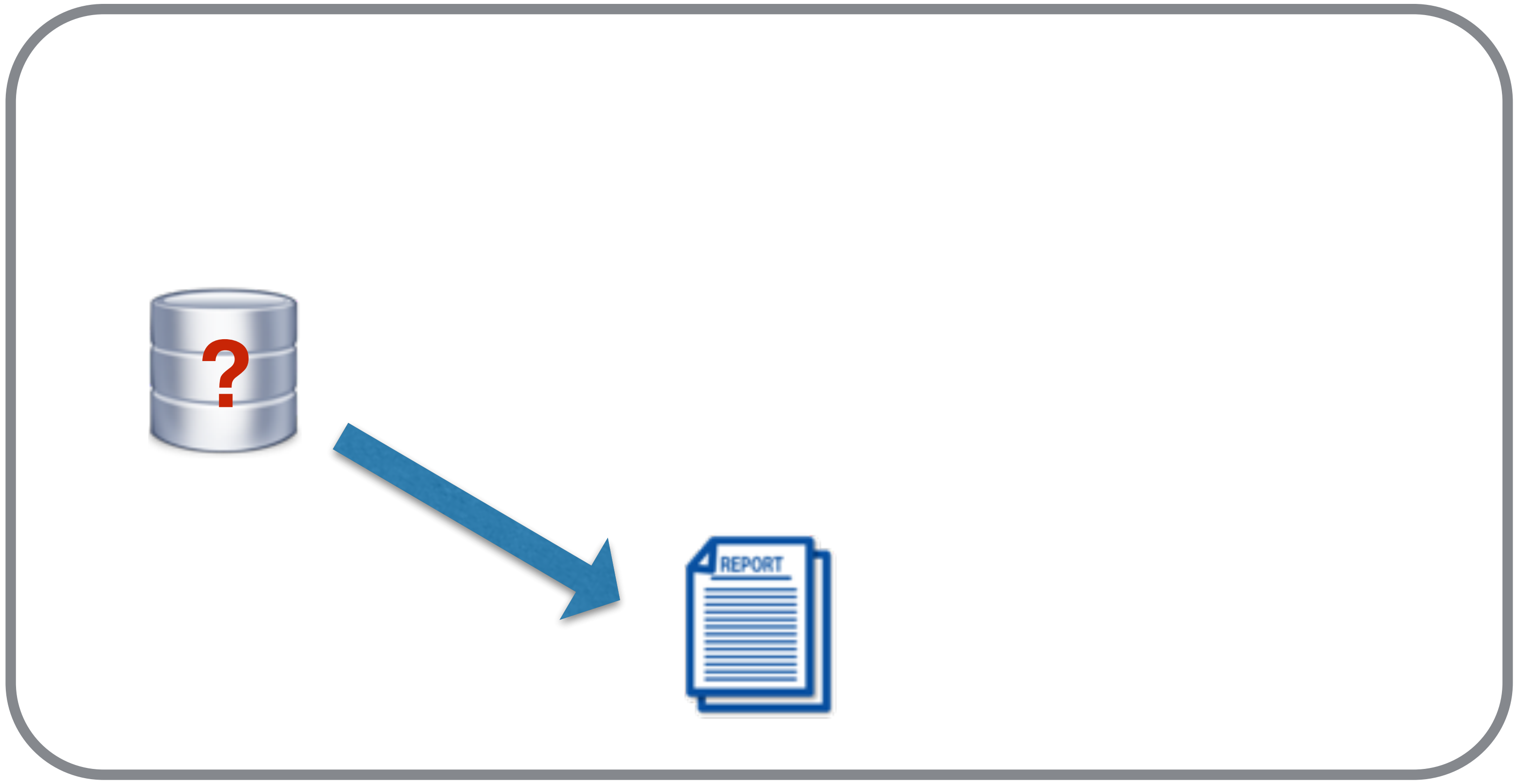

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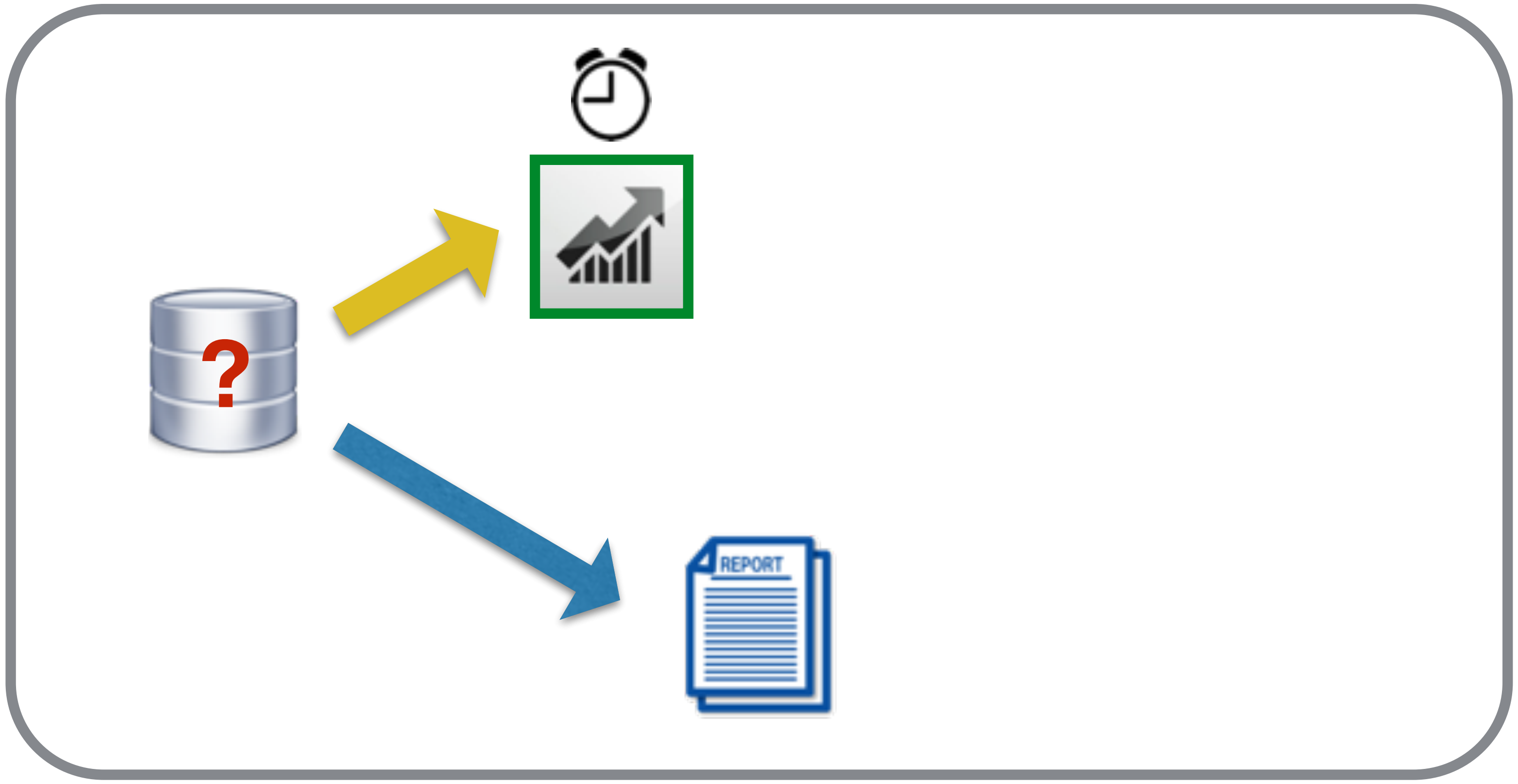

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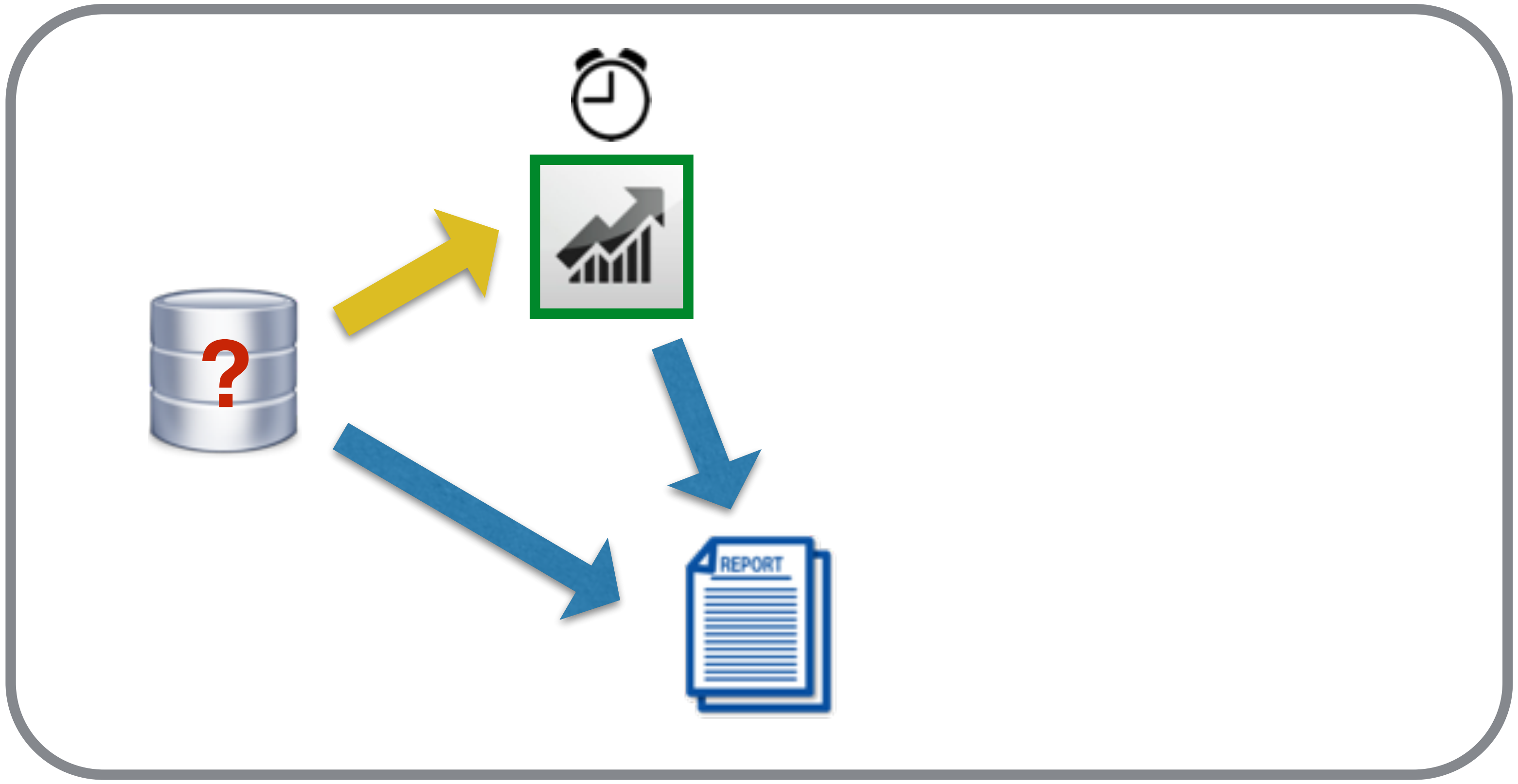

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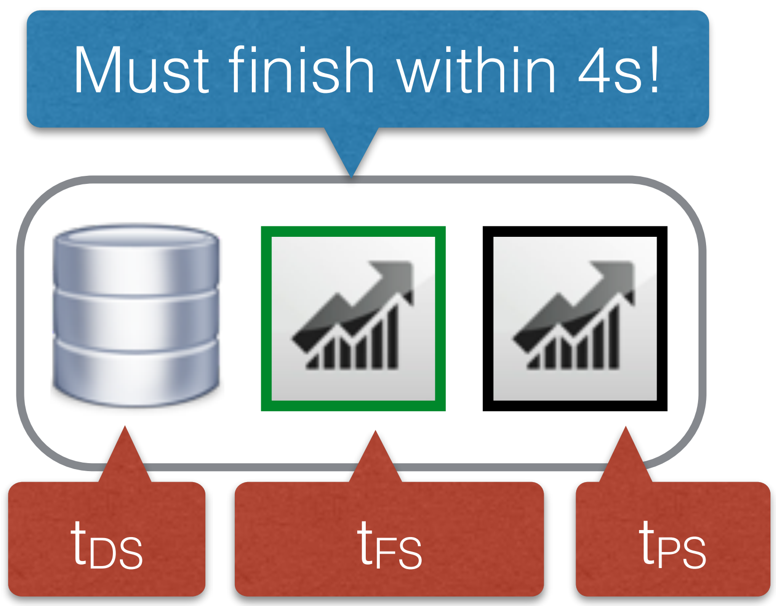

Previous Work:  [ICSE'13]

- *Local Timing Requirements (LTR) synthesis*
- *Web Services - BPEL*
- *Monolithic representation*

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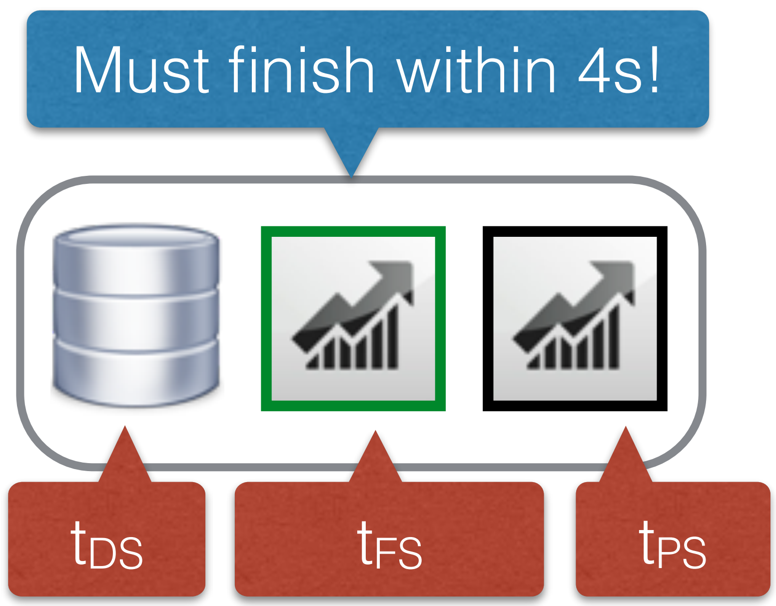

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LTR:

$$\neg(0 \le t_{DS} \wedge 1 \le t_{FS} \wedge 1 \le t_{PS})$$
$$\wedge((0 \le t_{DS} \wedge 0 \le t_{FS} \wedge 0 \le t_{PS}) \Rightarrow t_{DS} \le 3)$$
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Existing Approach: LTR

SE'13]

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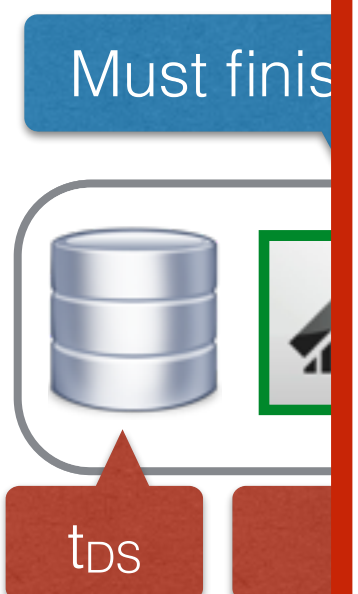

LTR - monolithic constraint

Pros:

\+ distills complicated composition structures into a single formula

\+ precisely captures all feasible combinations

Cons:

\- imposes dependencies across components

\- lacks support for localized debugging/repairing

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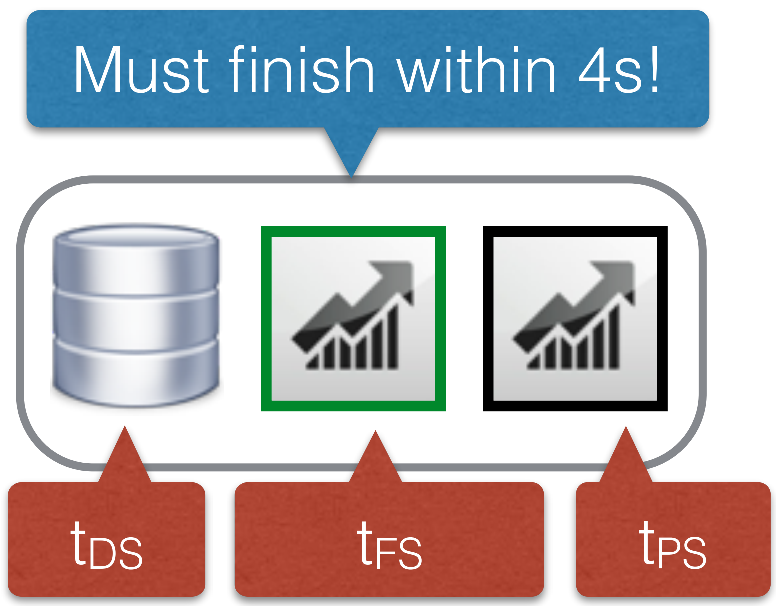

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uLTR:

$$(0 \leq t_{DS} < 1 \wedge 0 \leq t_{FS} < 1)$$
$$\vee(0 \leq t_{DS} < 1 \wedge 0 \leq t_{PS} < 1)$$

LTR vs. uLTR

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- *Component-dependent timing requirement*
- *Linear real arithmetic*
- *Precise*
- *Monolithic*

uLTR:

$$(0 \le t_{DS} < 1 \wedge 0 \le t_{FS} < 1)$$
$$\vee(0 \le t_{DS} < 1 \wedge 0 \le t_{PS} < 1)$$

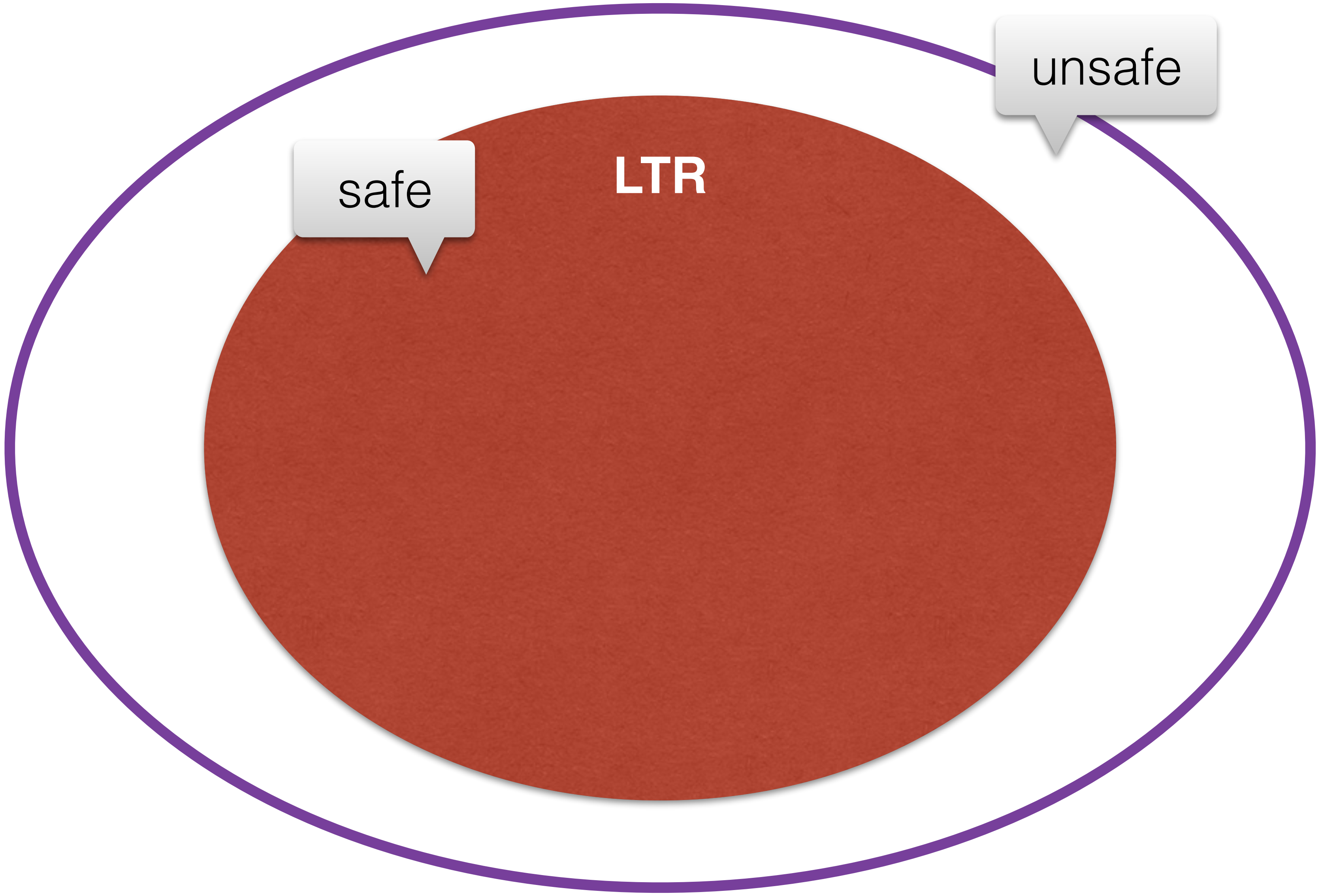
- *Component-independent under-approximated LTR*
- *Intervals*
- *Under-approximated*
- *Localized*

LTR vs. uLTR

All possible timing configurations,

e.g., $t_{DS} = 1$, $t_{FS} = 0.5$, $t_{PS} = 0.8$

LTR vs. uLTR



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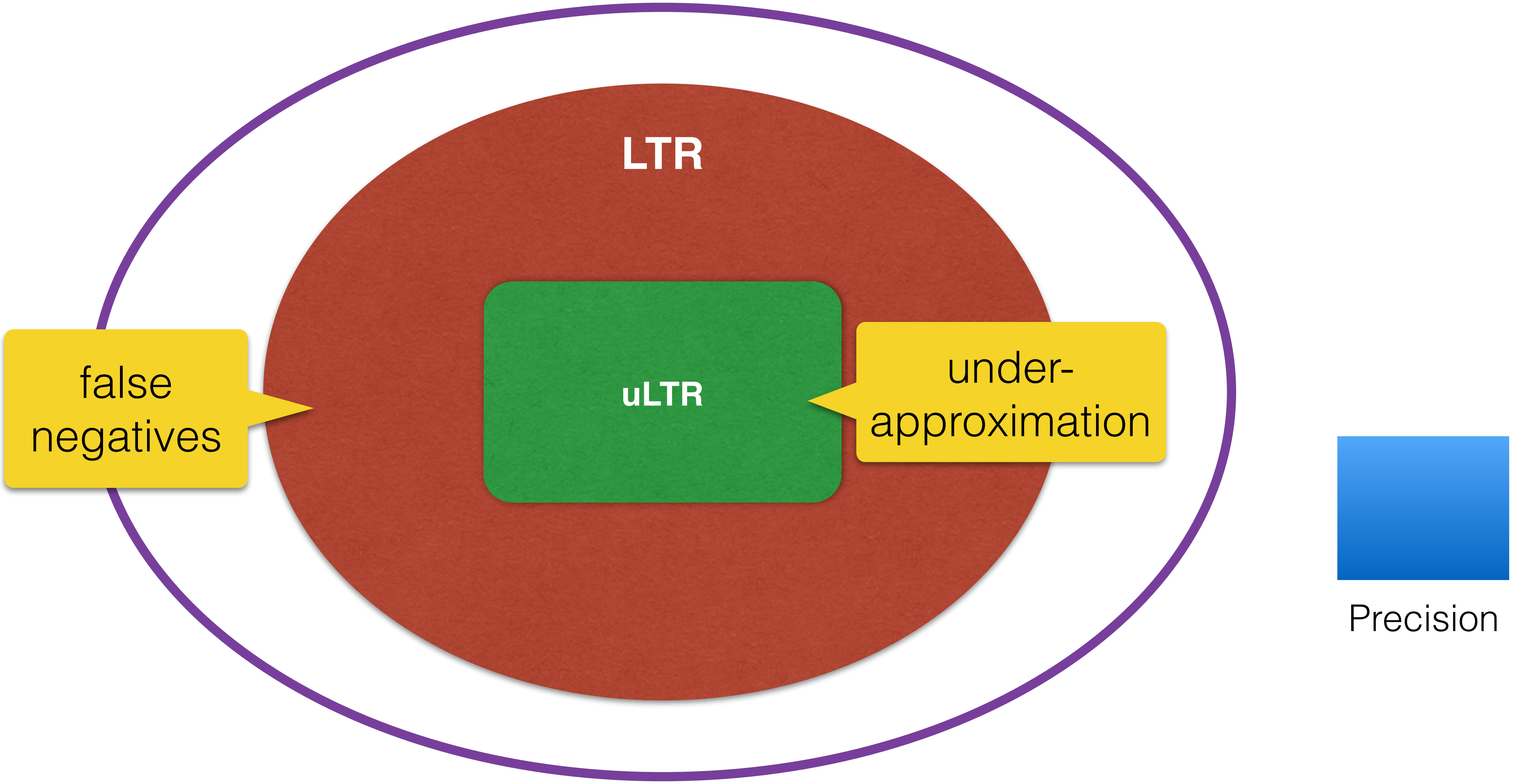

$$\text{Precision}(\text{uLTR}) = \frac{\#\text{configurations satisfied by uLTR}}{\#\text{configurations satisfied by LTR}} \times 100\%$$

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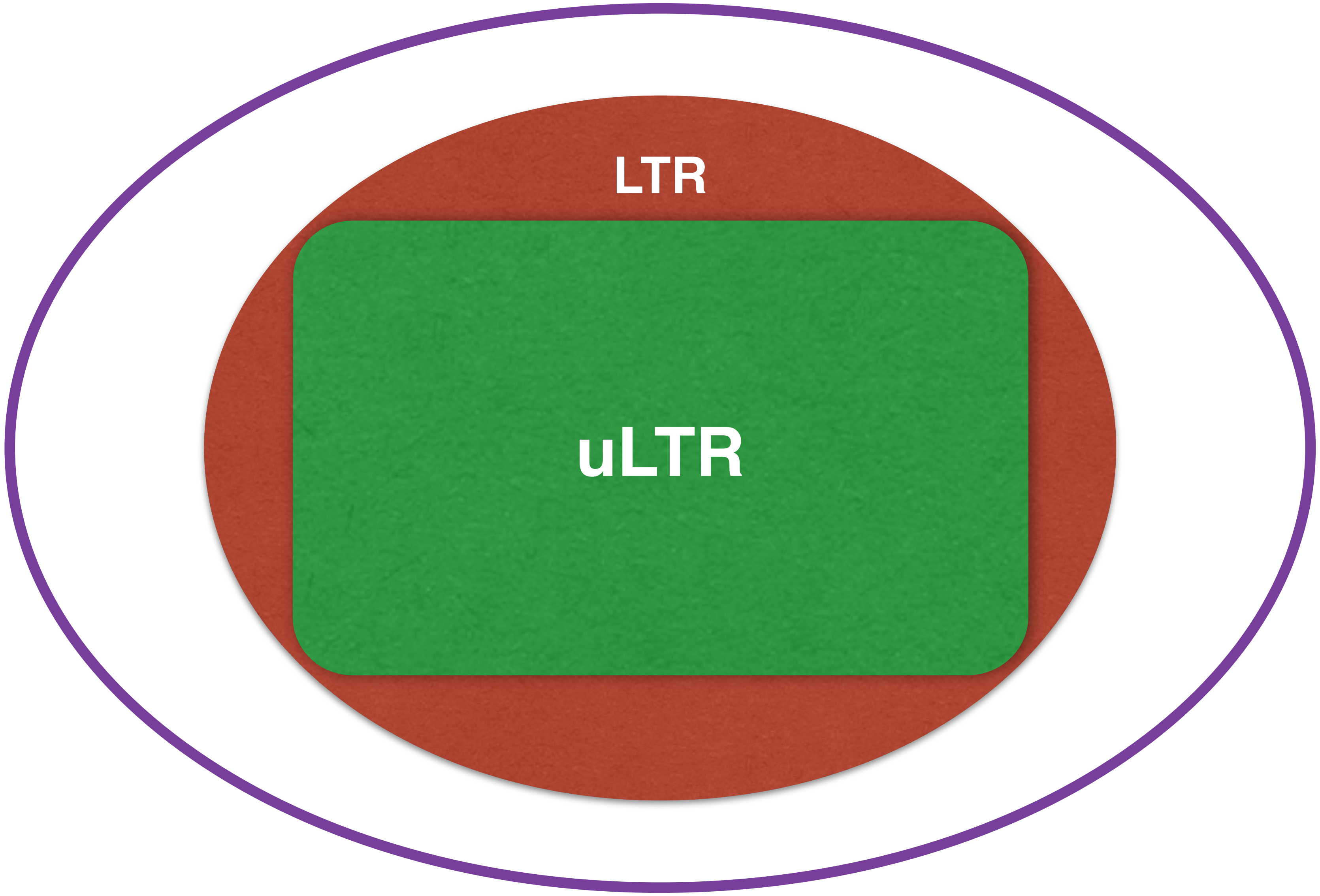

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Checklist

☐ What is uLTR?

- *Component-independent under-approximated LTR*
- *Soundness: ensure timing safety*

☐ How to break up the monolithic constraint?

- *Compute uLTR from LTR*
- *Precision: preserve as many choices as possible*

☐ How can localized constraints support the management of timing requirements?

- *uLTR for component selection*
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Compute uLTR from LTR

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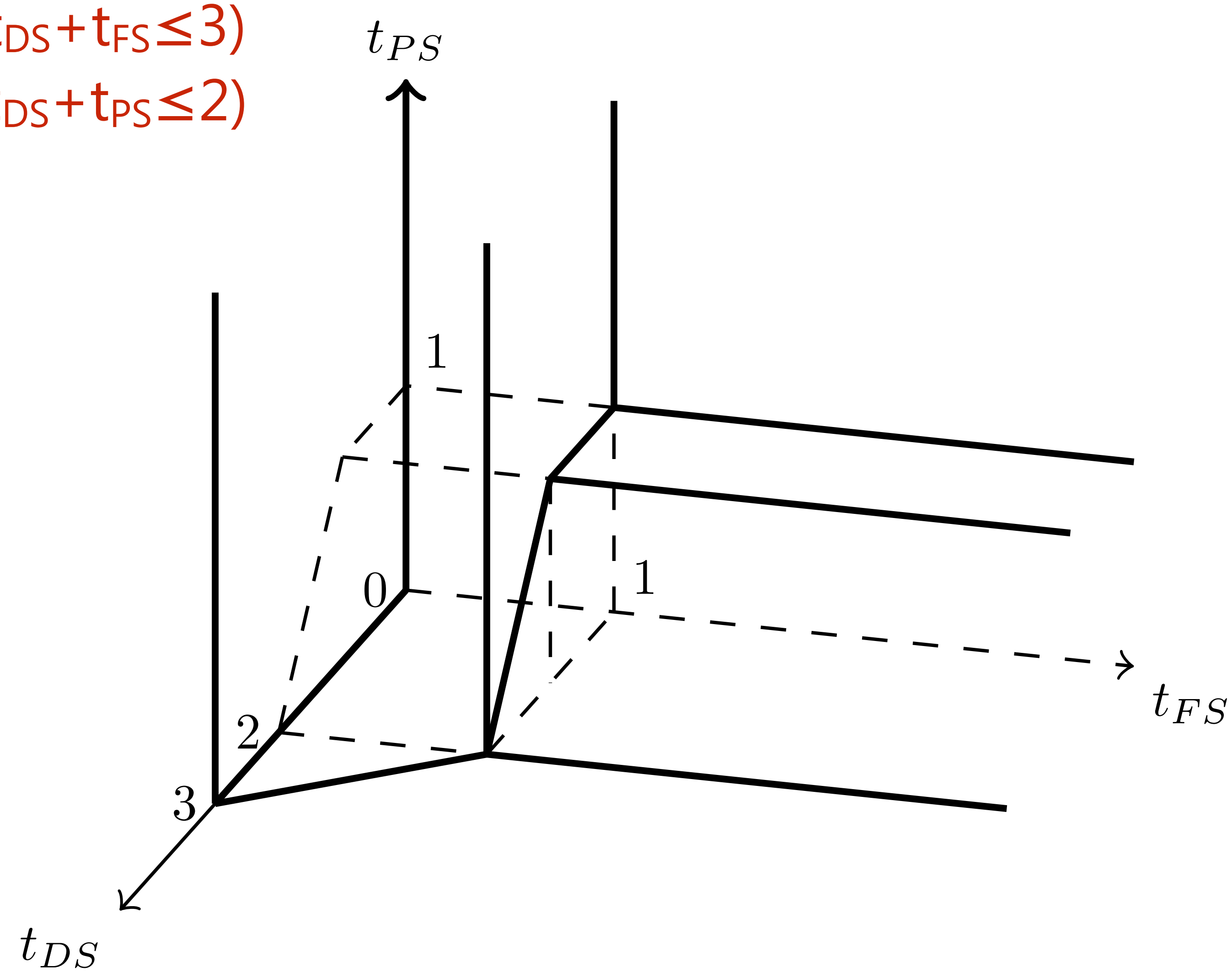

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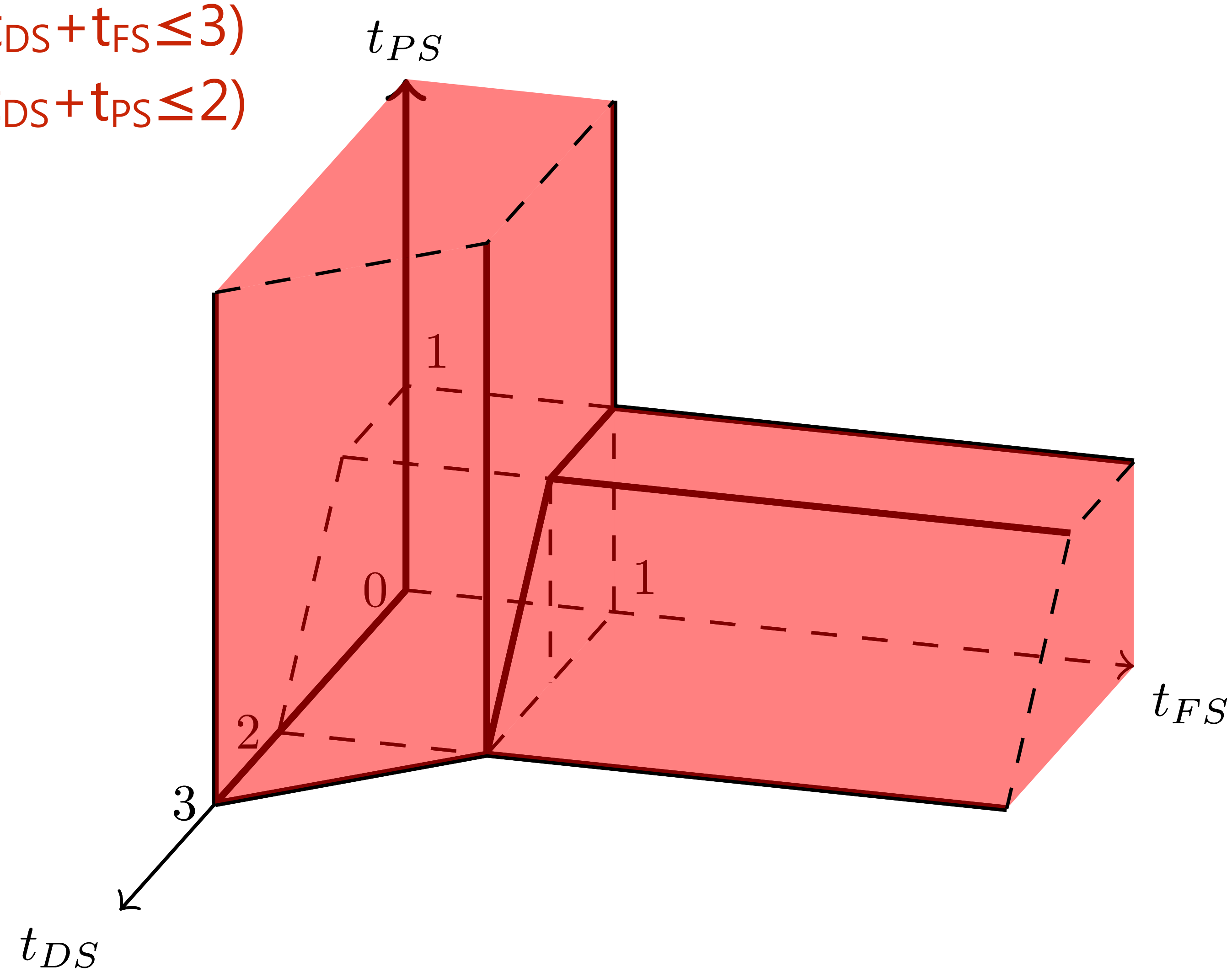

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B:

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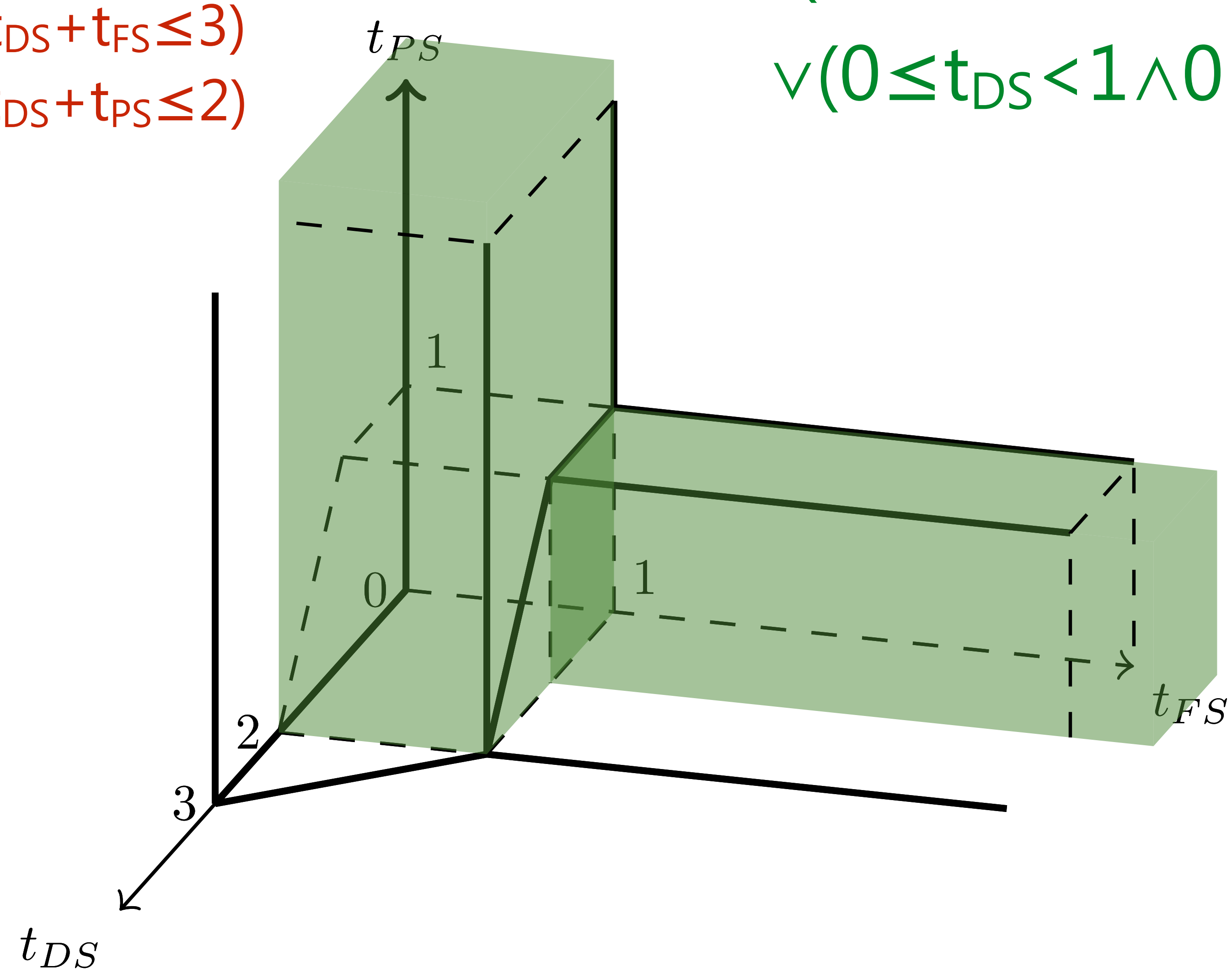

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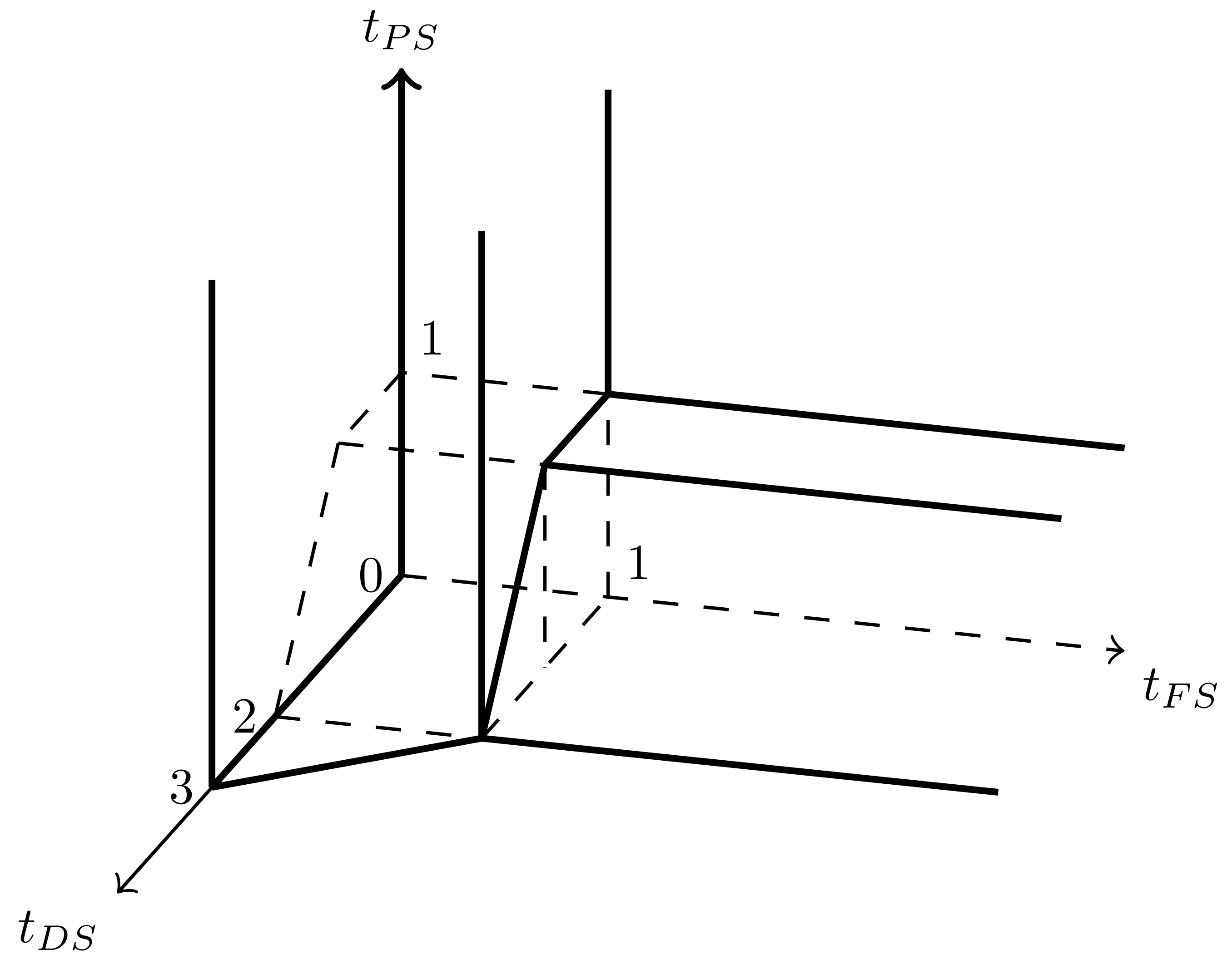
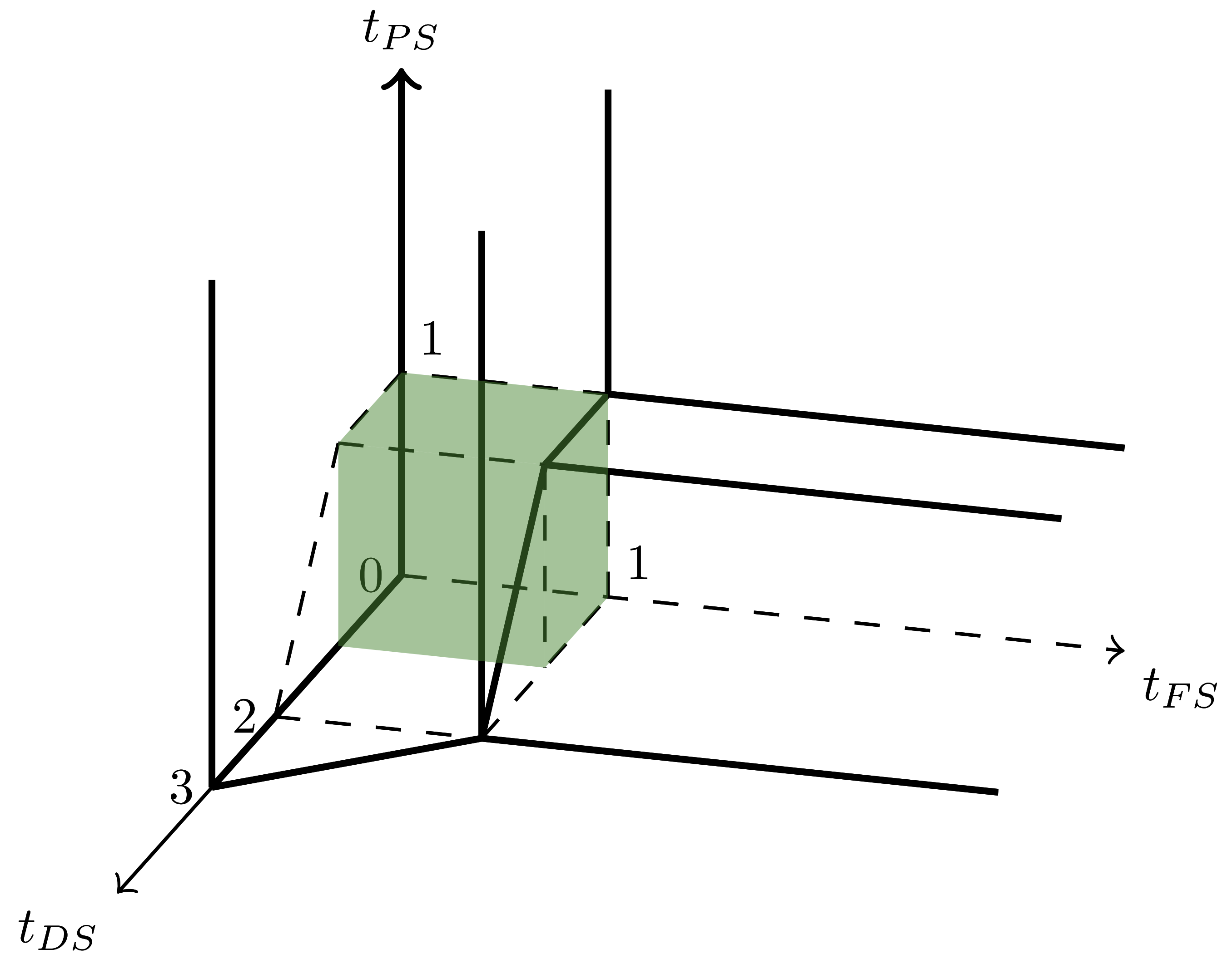


Compute uLTR from LTR

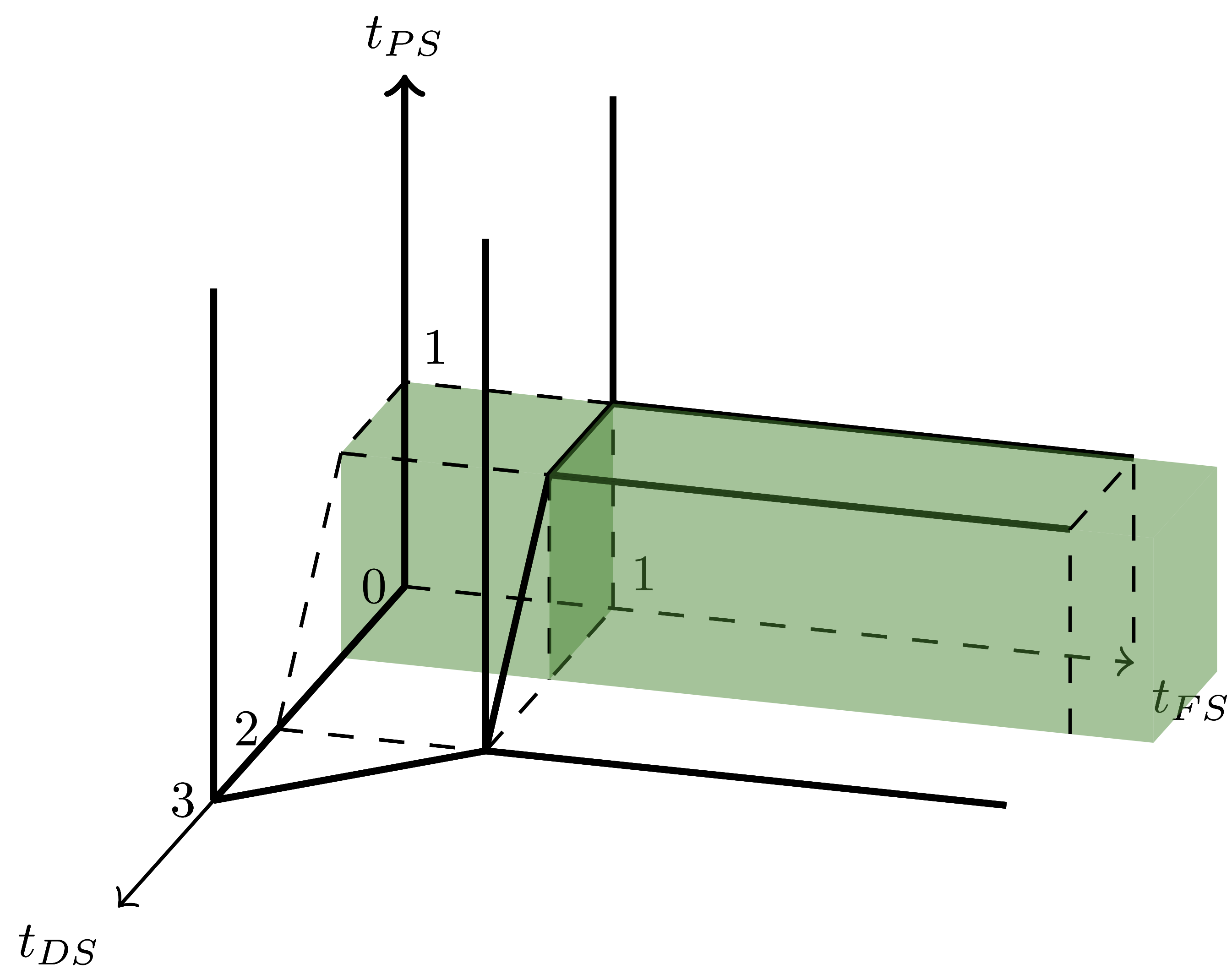
B_1= MaxCube(φ)



Compute uLTR from LTR

B_1= MaxCube(φ)

InfCube(φ,B_1)

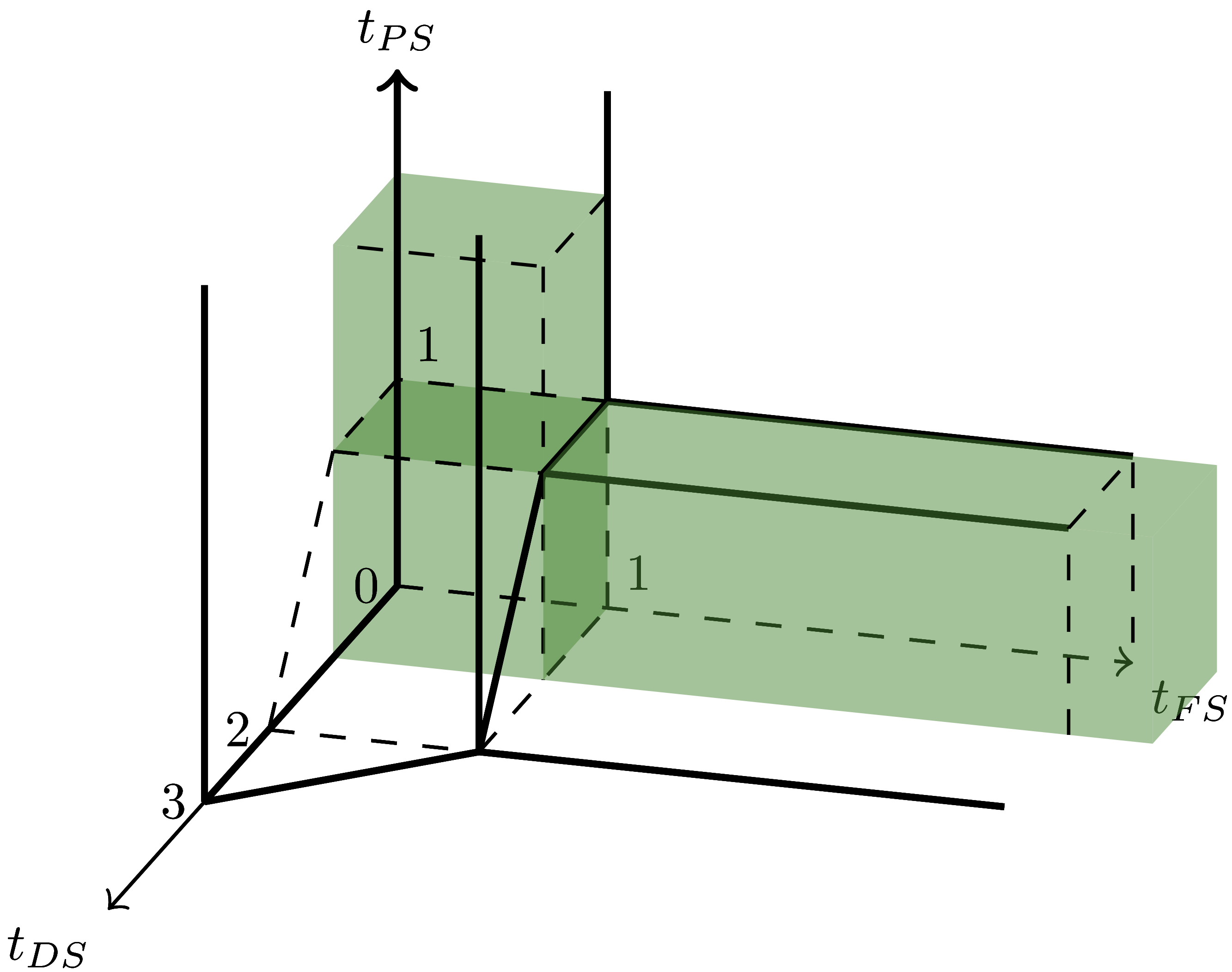


Compute uLTR from LTR

B₁= MaxCube(φ)

InfCube(φ,B₁)

B₂= MaxCube(φ)



Compute uLTR from LTR

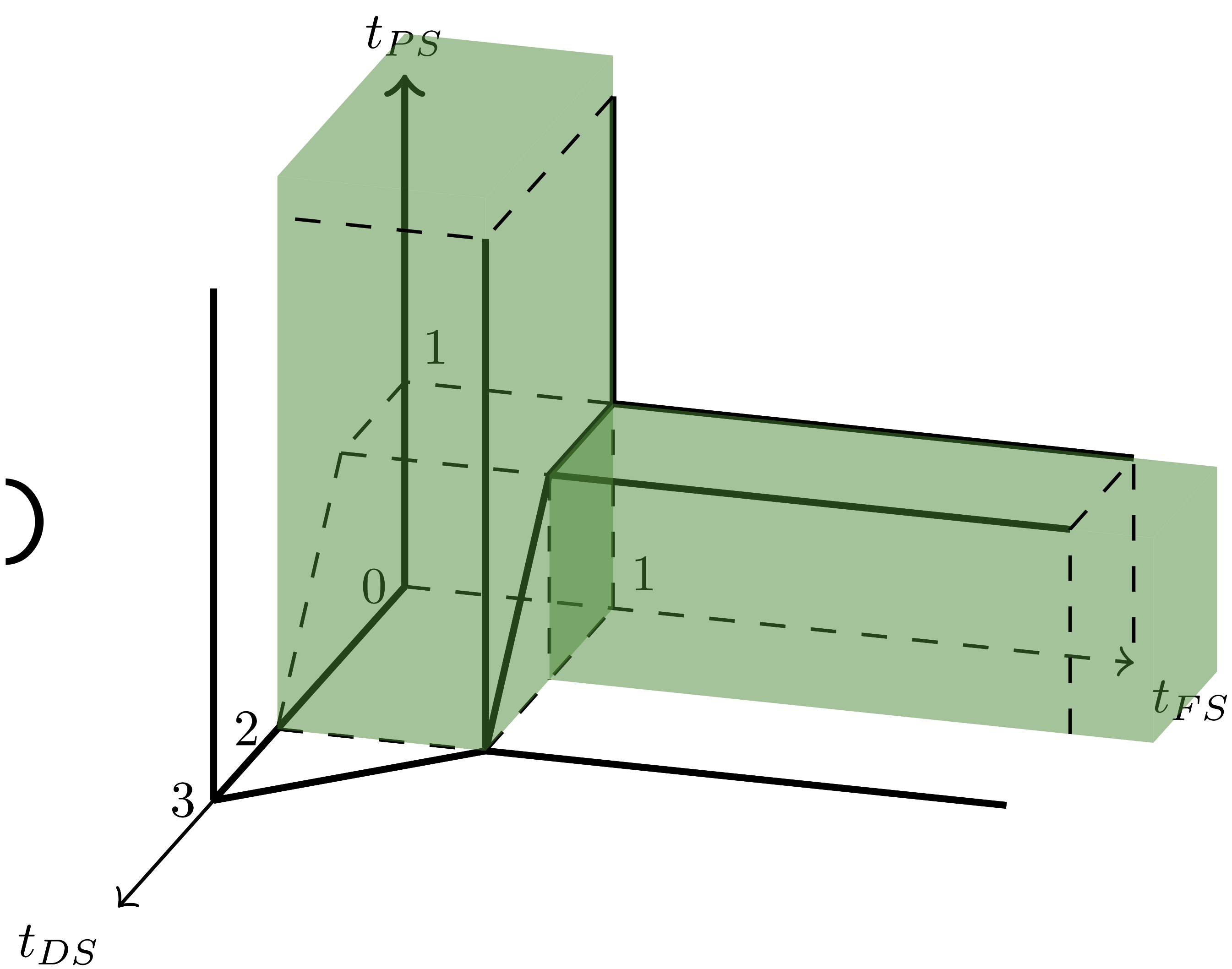
B_1= MaxCube(φ)

InfCube(φ,B_1)

B_2= MaxCube(φ)

…

B=Merge(B_1,…,B_i)



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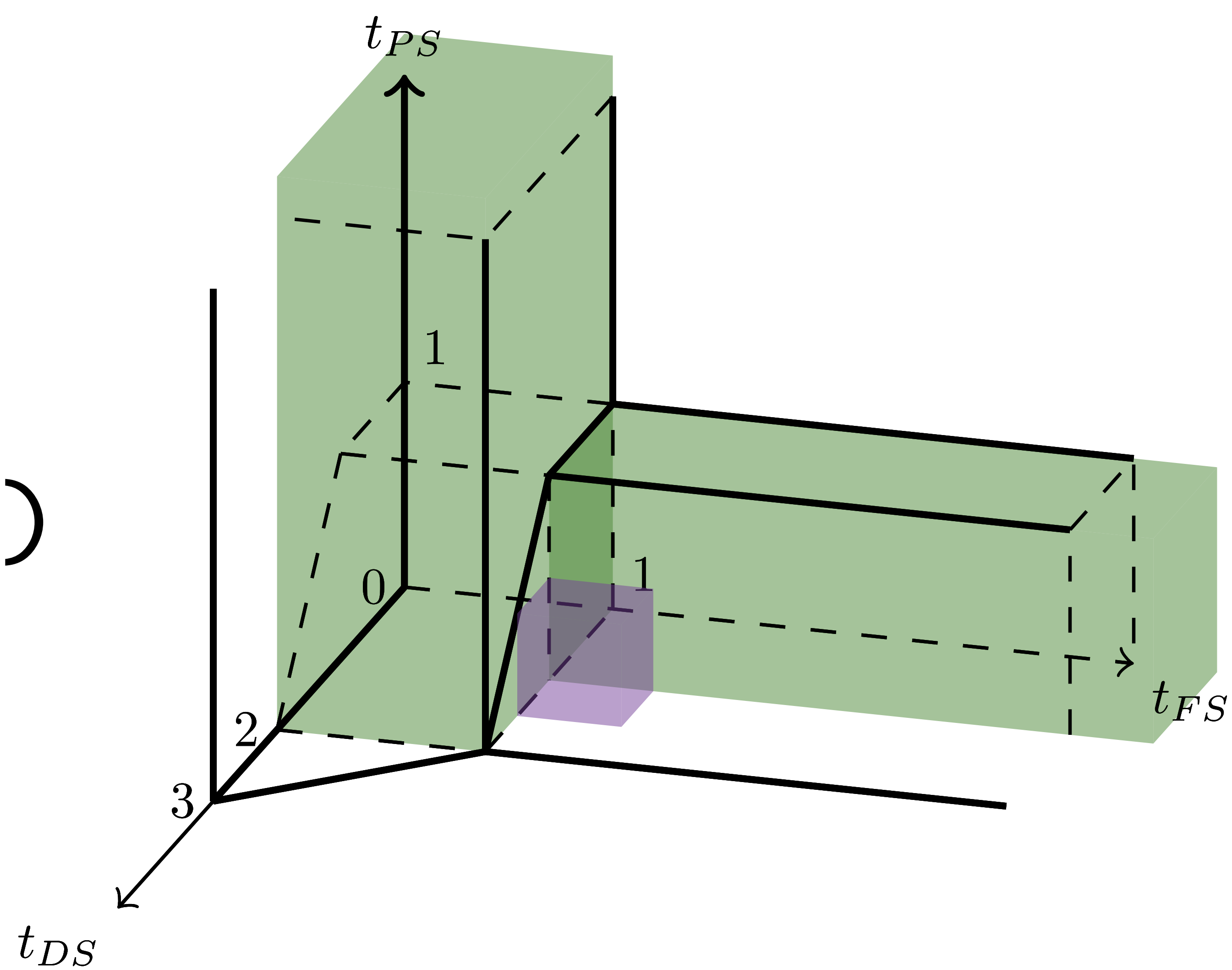
…

B=Merge(B_1,…,B_i)

if (h(B_i)<ω)
   return;



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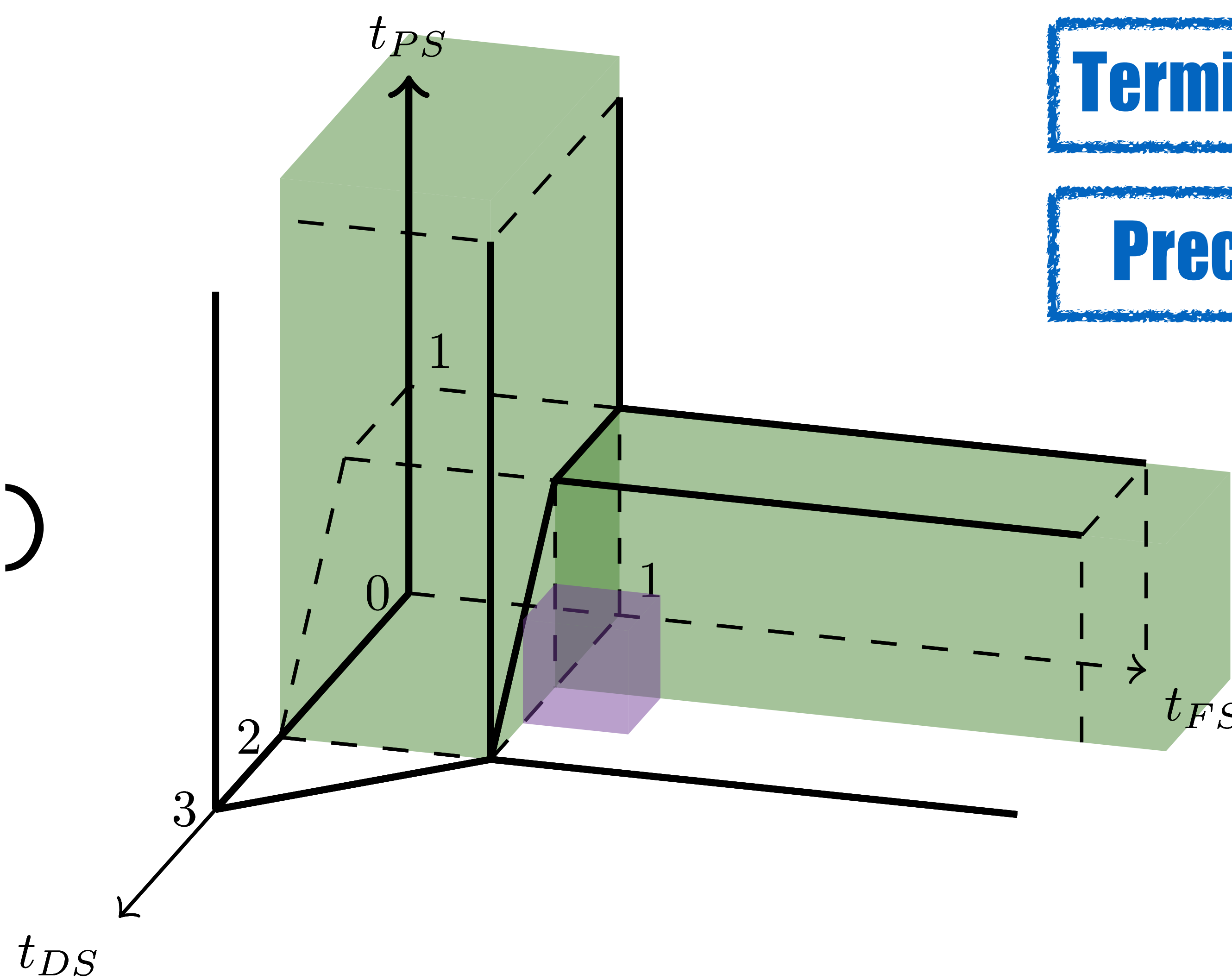

Soundness

Termination

Precision

SMT Encodings

```
MaxCube(φ) //return the hypercube in φ with maximum volume
```

```
InfCube(φ,B) //relax in one direction if possible
```

SMT Encodings

MaxCube(φ) //return the hypercube in φ with maximum volume

// sample arbitrary hyper-rectangle

$$\theta \triangleq \forall Vars(\varphi) \cdot \left(\left(\bigwedge_{v_i \in Vars(\varphi)} l_i \le v_i \le u_i\right) \Rightarrow \varphi\right)$$

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```
    // sample maximal hyper-cube
```

$$\textsc{Optimize}(\theta \wedge (\bigwedge_{v_i \in Vars(\varphi)} (u_i - l_i = h)), h)$$

```
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Symbolic Optimization

[POPL'14]

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InfCube(φ,B) //relax in one direction if possible

$\textsc{unSAT?}\ (\neg(B[l_i/\infty] \Rightarrow \varphi))$ // relax lower bound

$\textsc{unSAT?}\ (\neg(B[u_i/\infty] \Rightarrow \varphi))$ // relax upper bound

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// heights of sampled hyper-cubes form a non-increasing sequence

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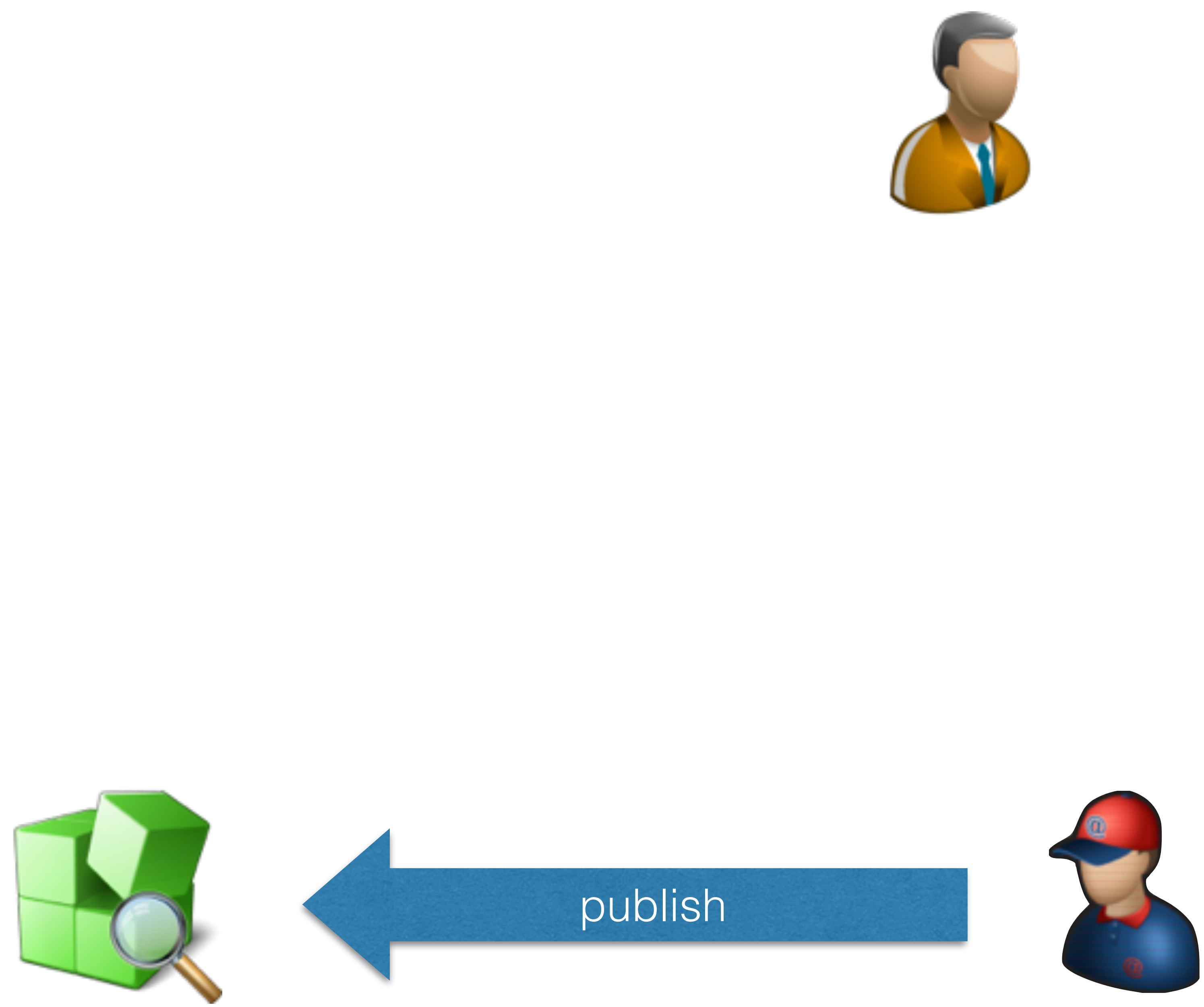

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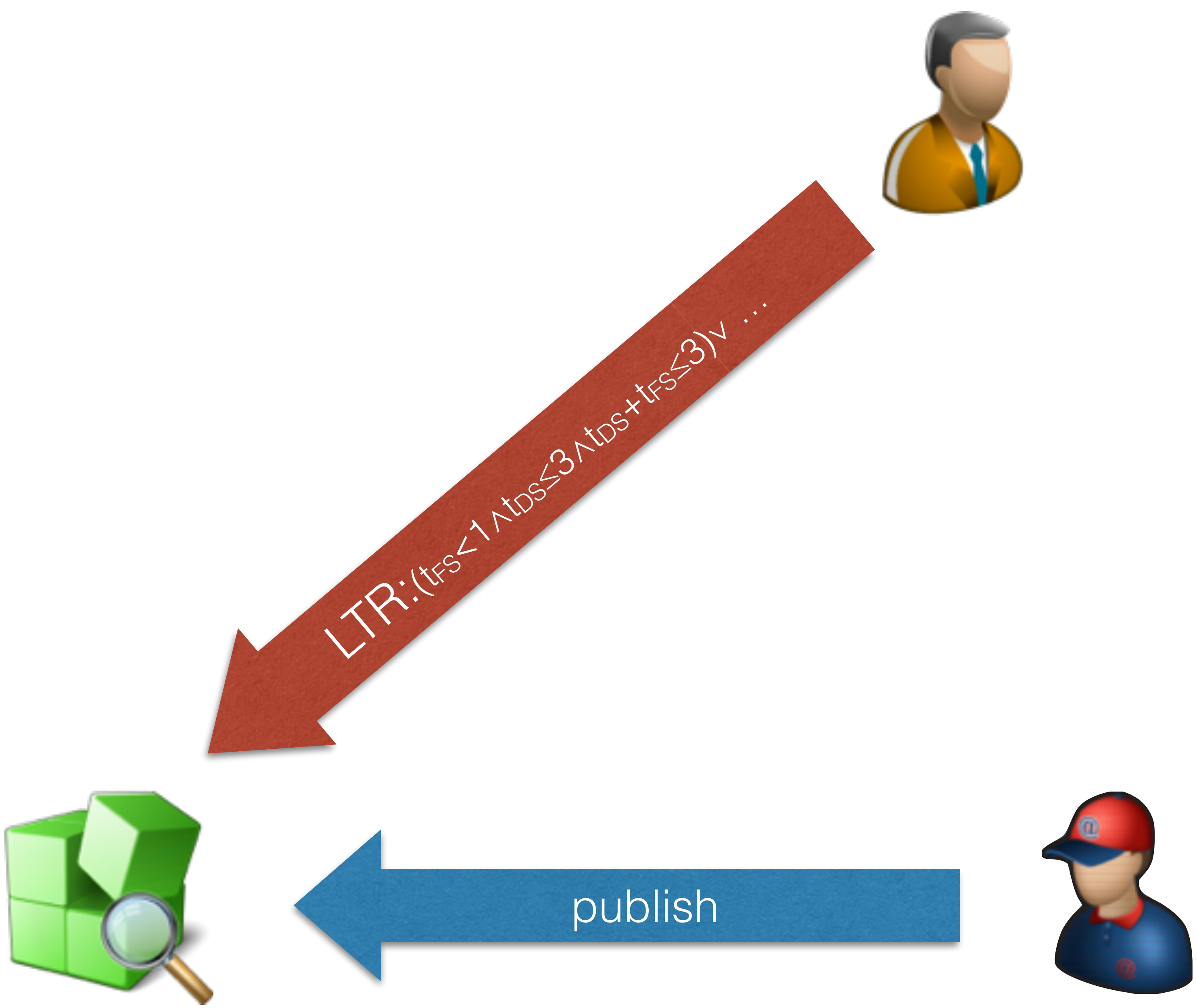

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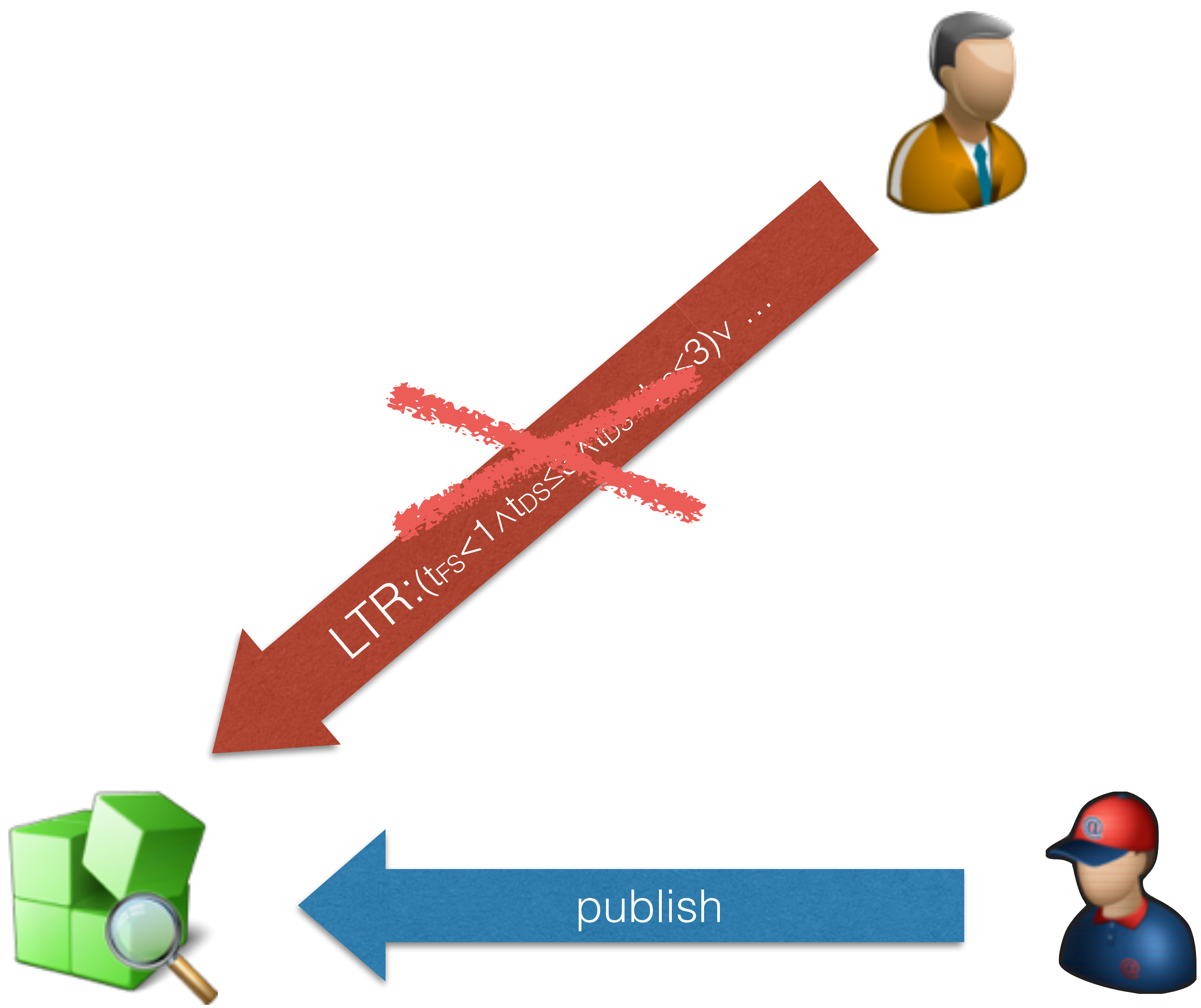
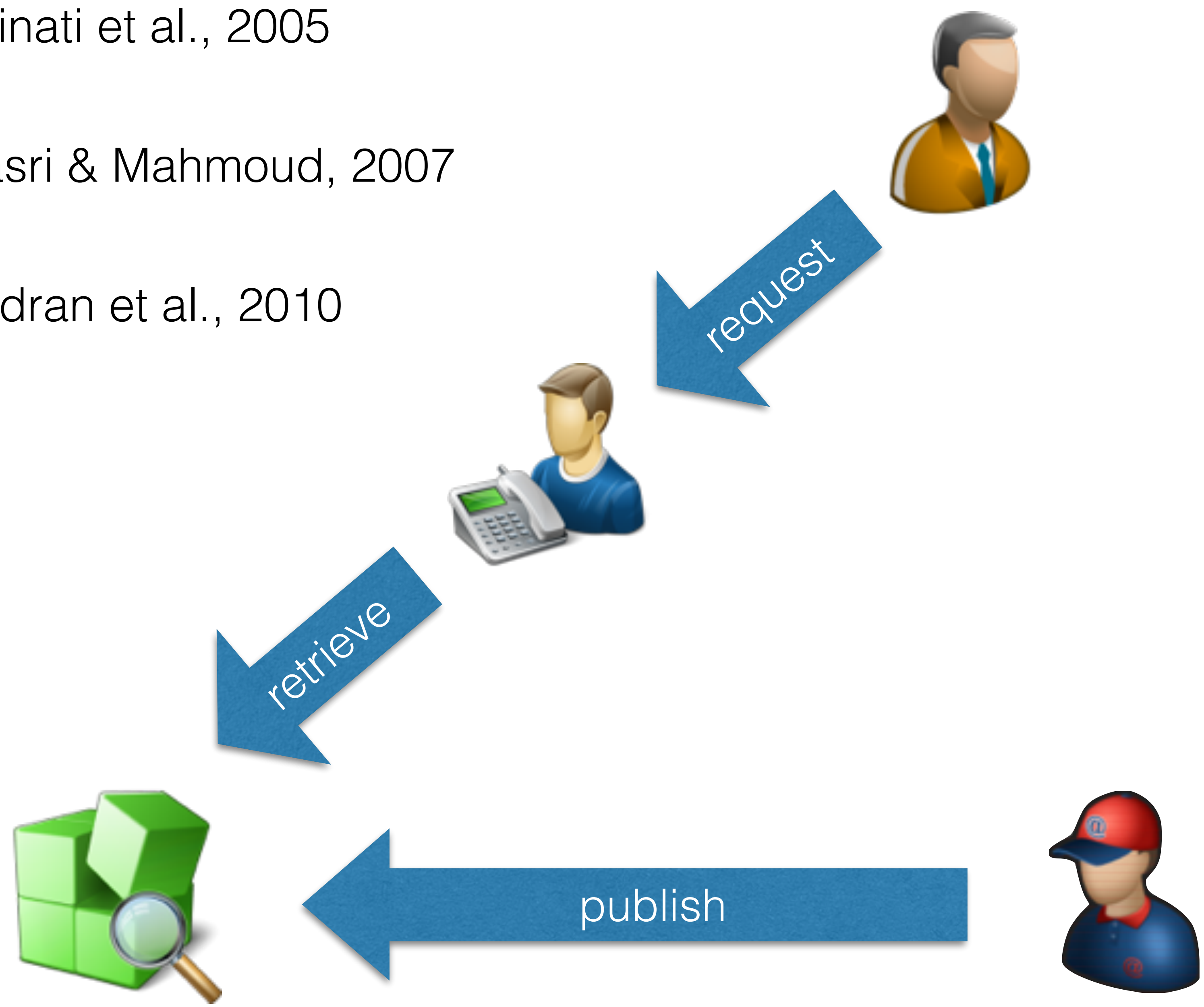


uLTR for component selection

- Carminati et al., 2005
- Al-Masri & Mahmoud, 2007
- Rajendran et al., 2010



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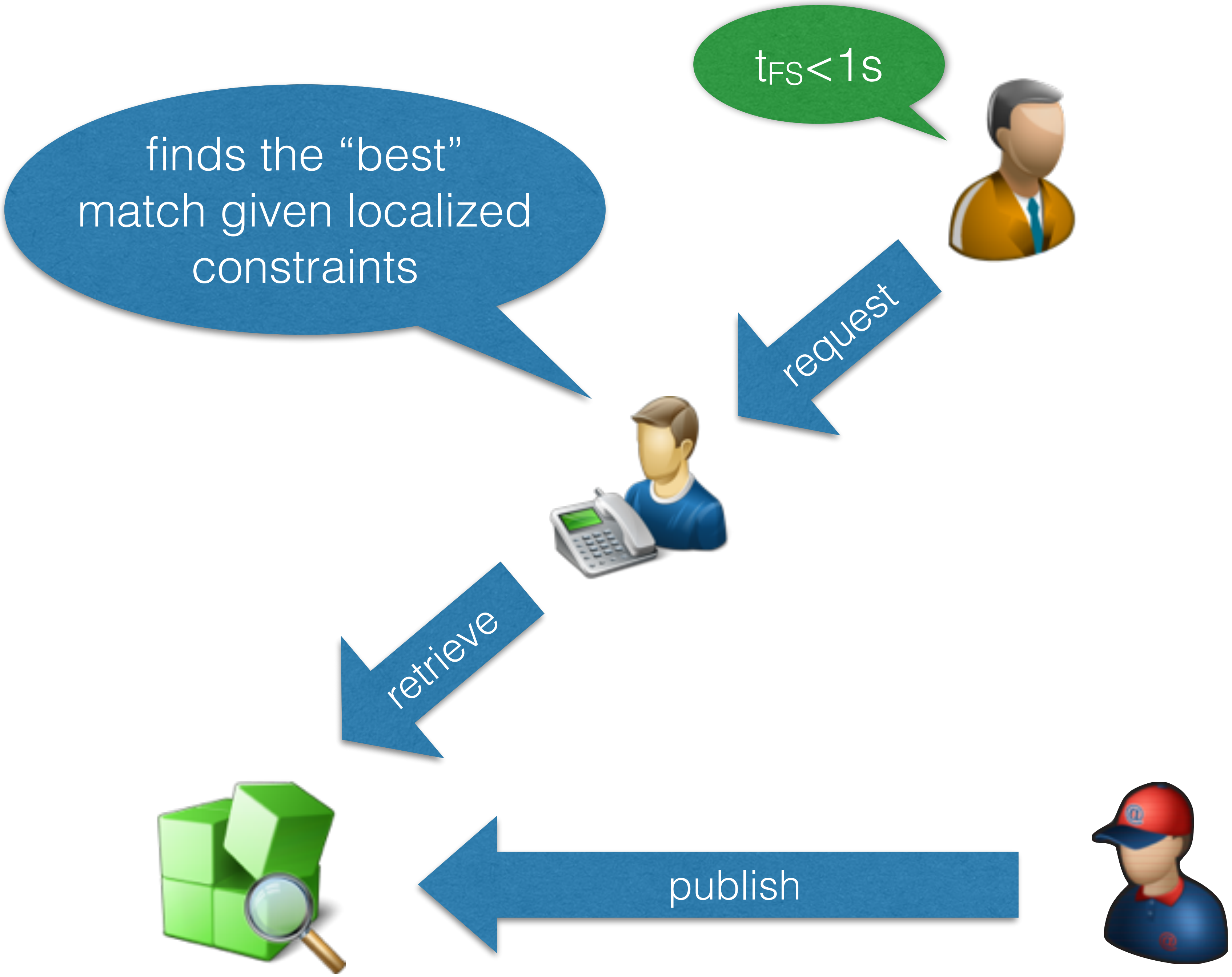

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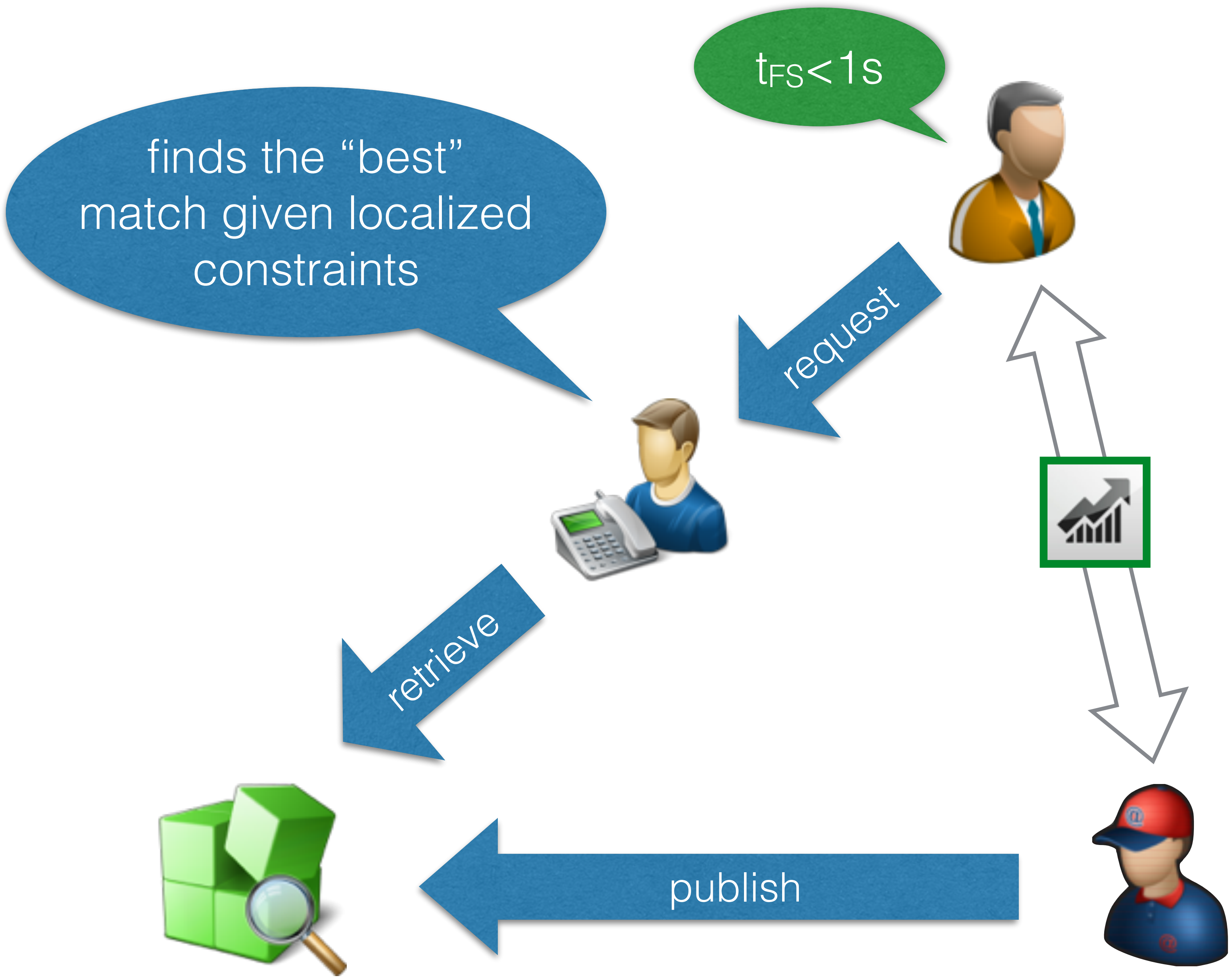
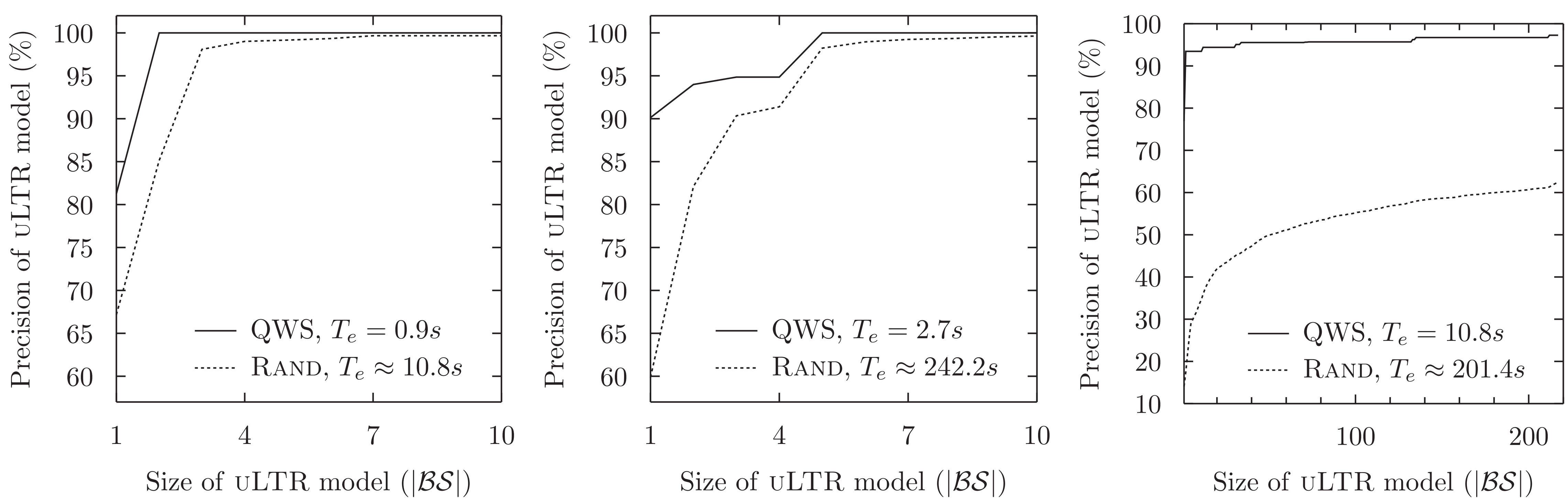


uLTR for component selection

- *Real-world Web Service data: QWS dataset*
- *Case studies: online booking service, …*
- *Evaluate the percentage of false-negatives (precision) w.r.t. size of the uLTR model*



uLTR for component selection

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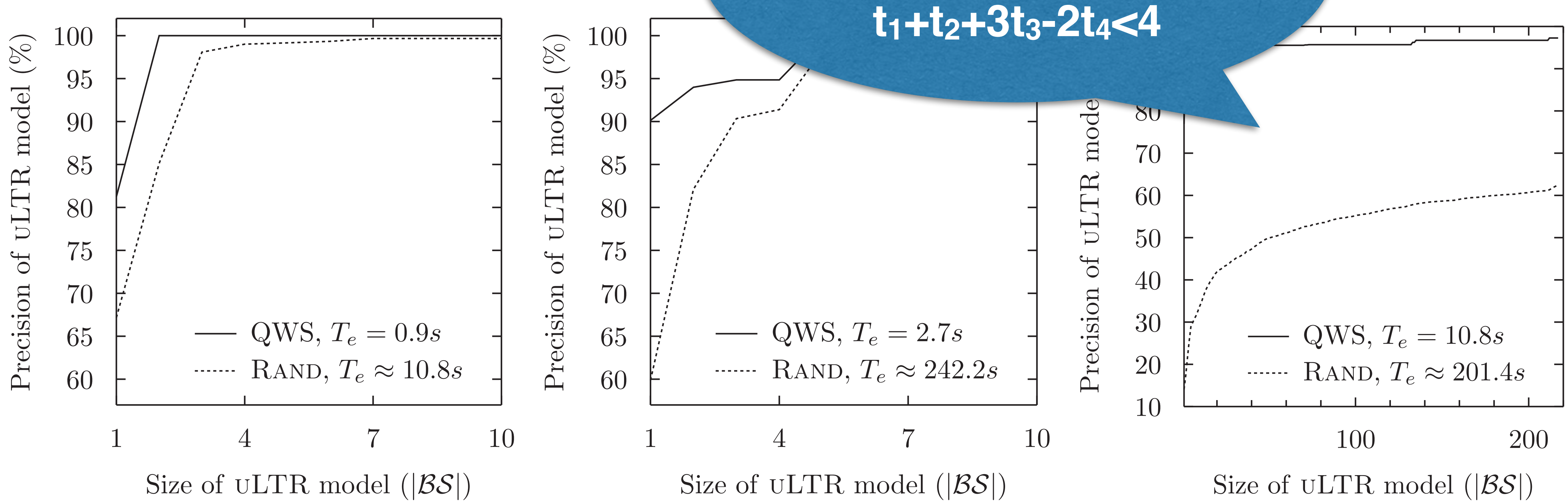
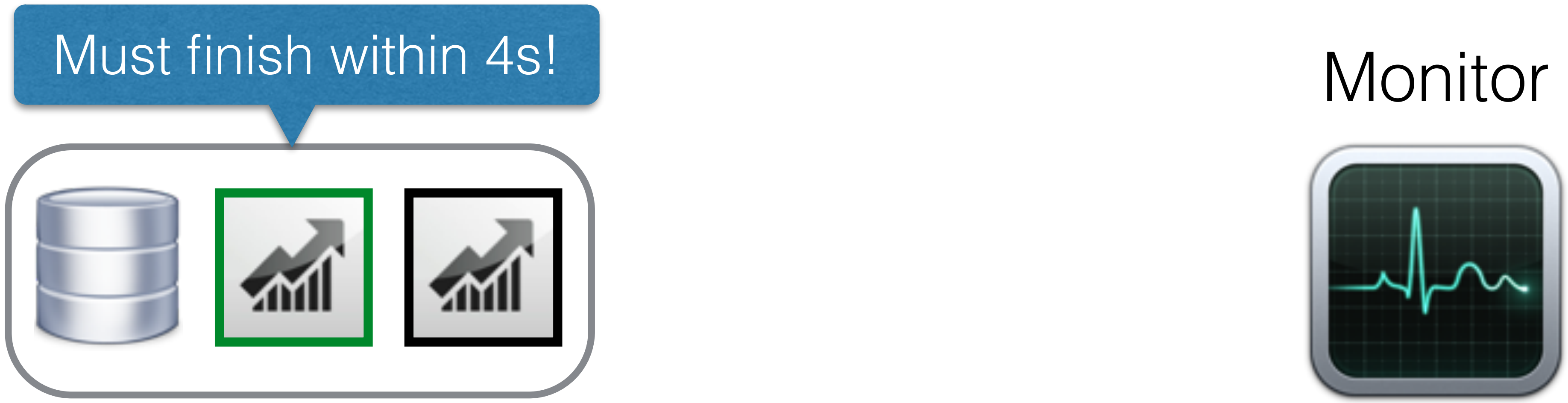
Strong dependency in the original LTR:
$t_1+t_2+3t_3-2t_4<4$



uLTR for runtime adaptation and recovery



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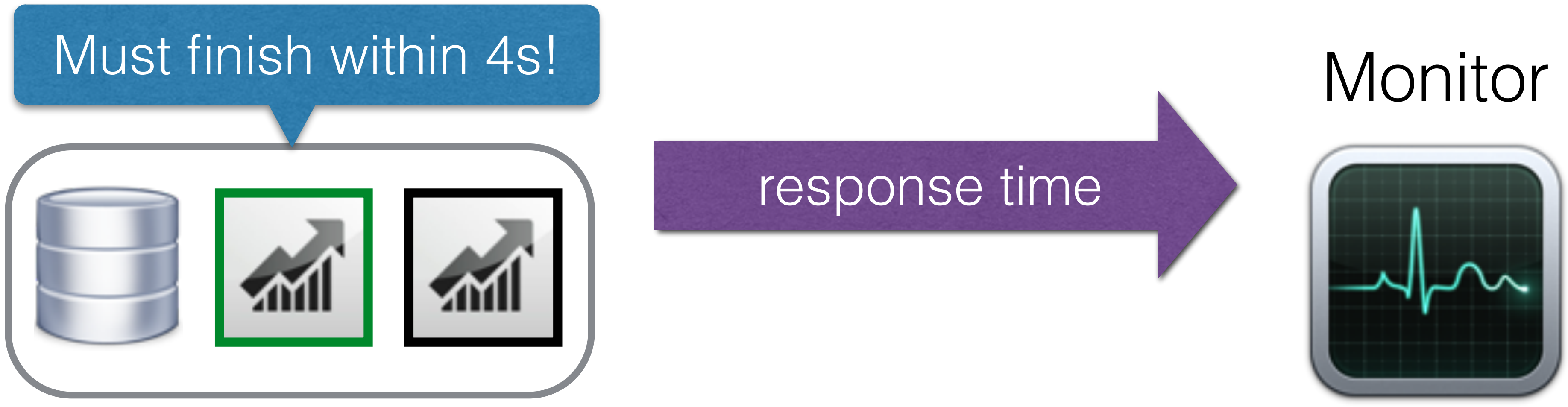

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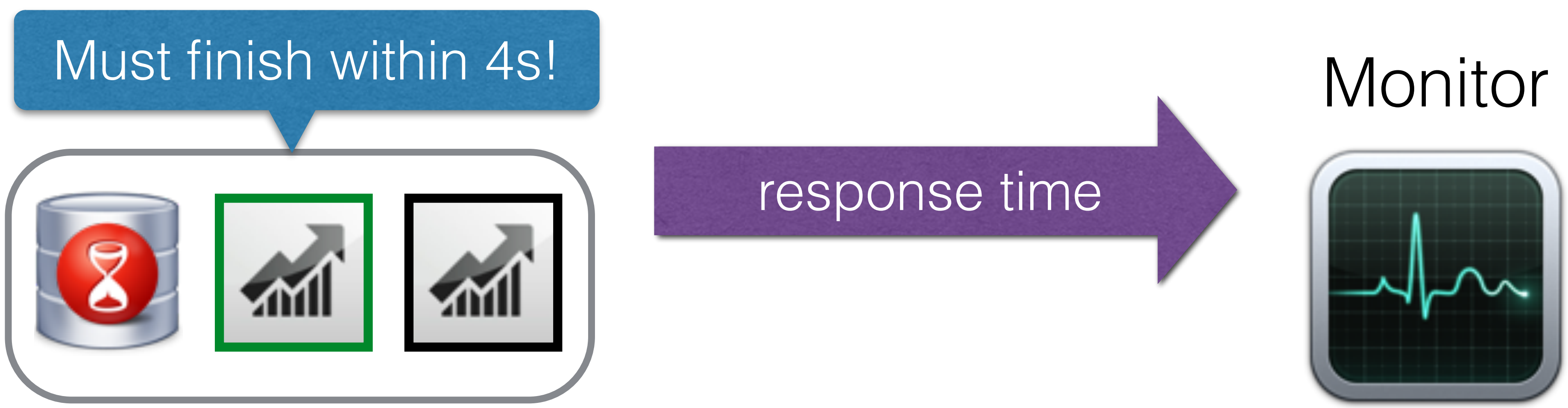

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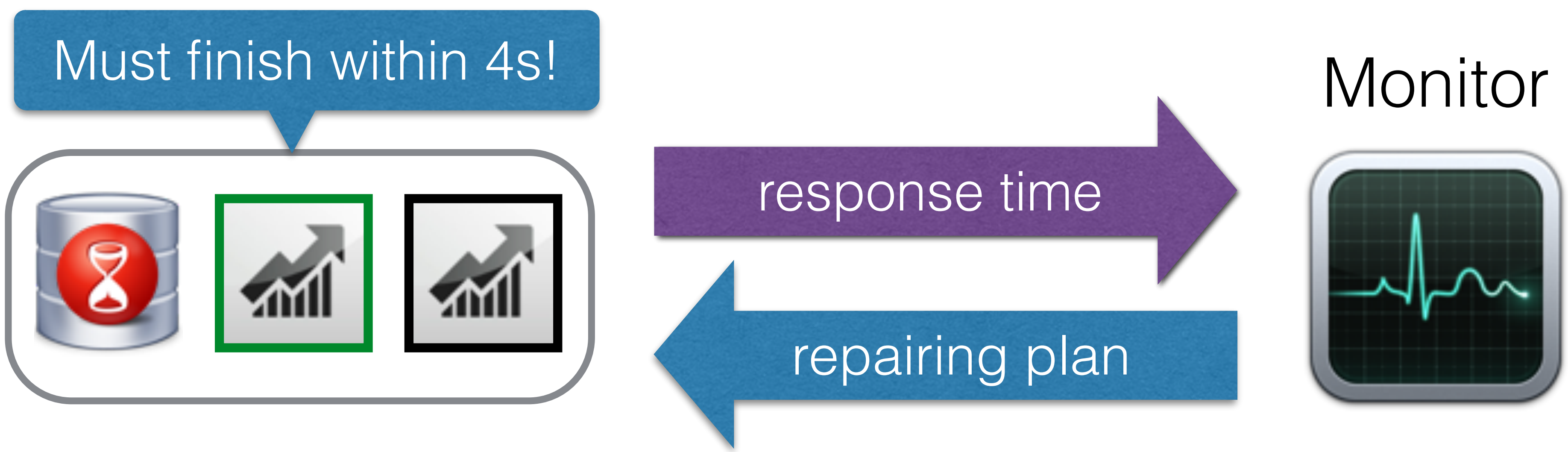

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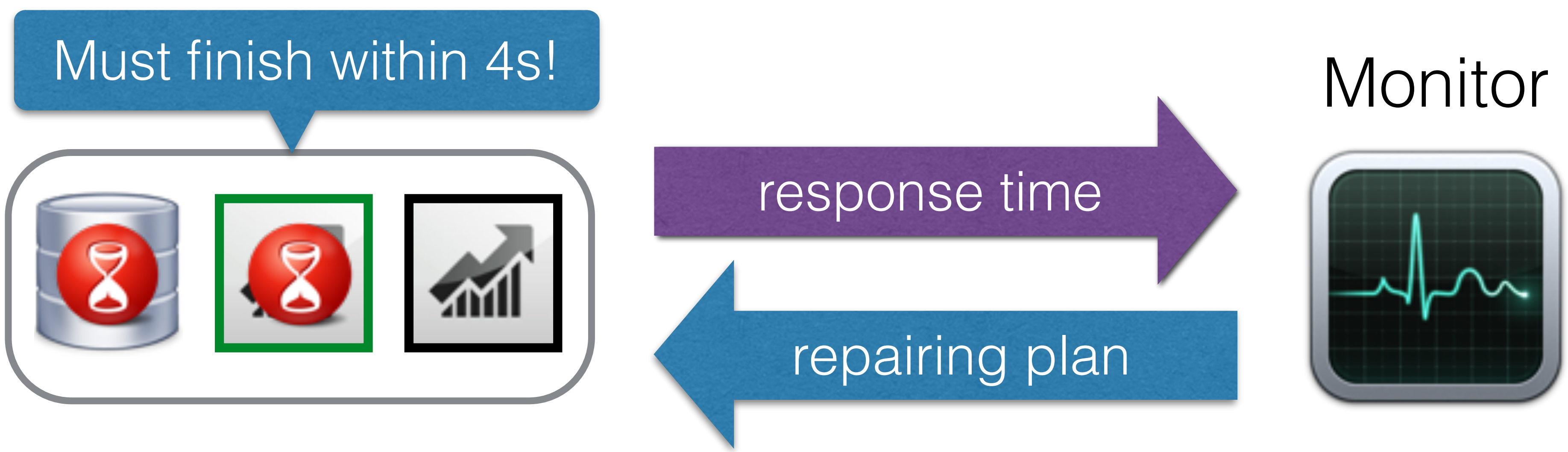

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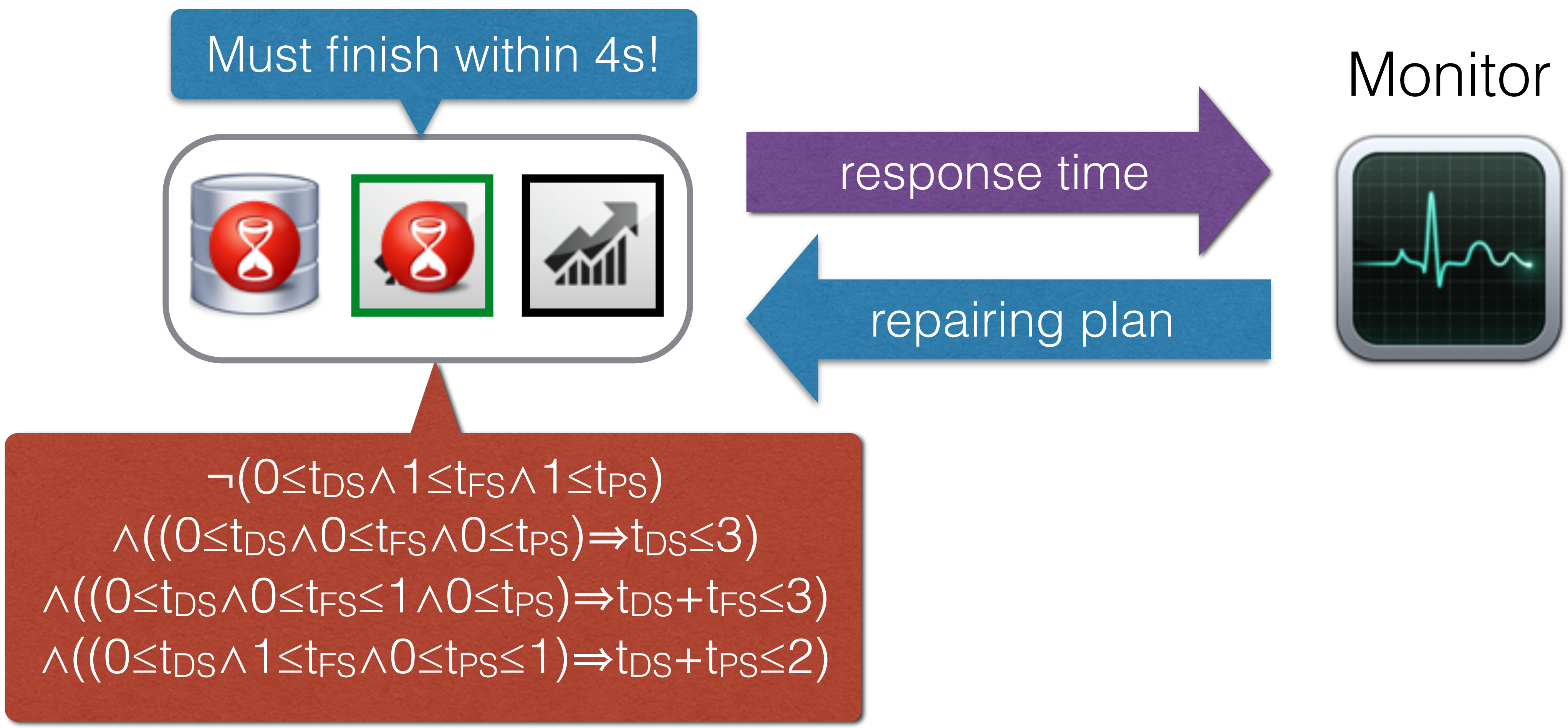

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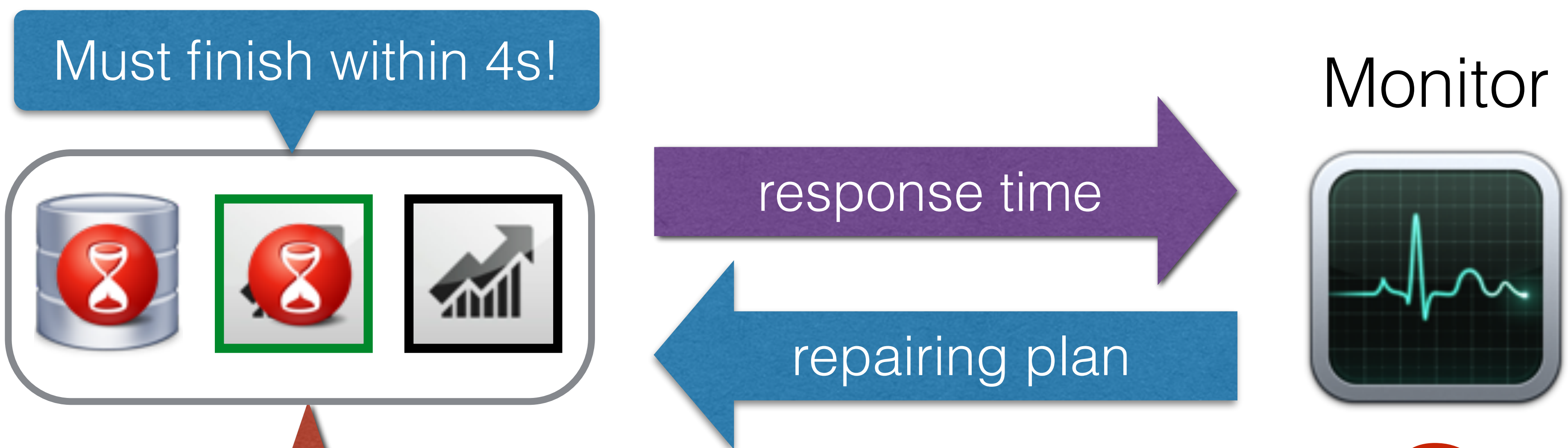
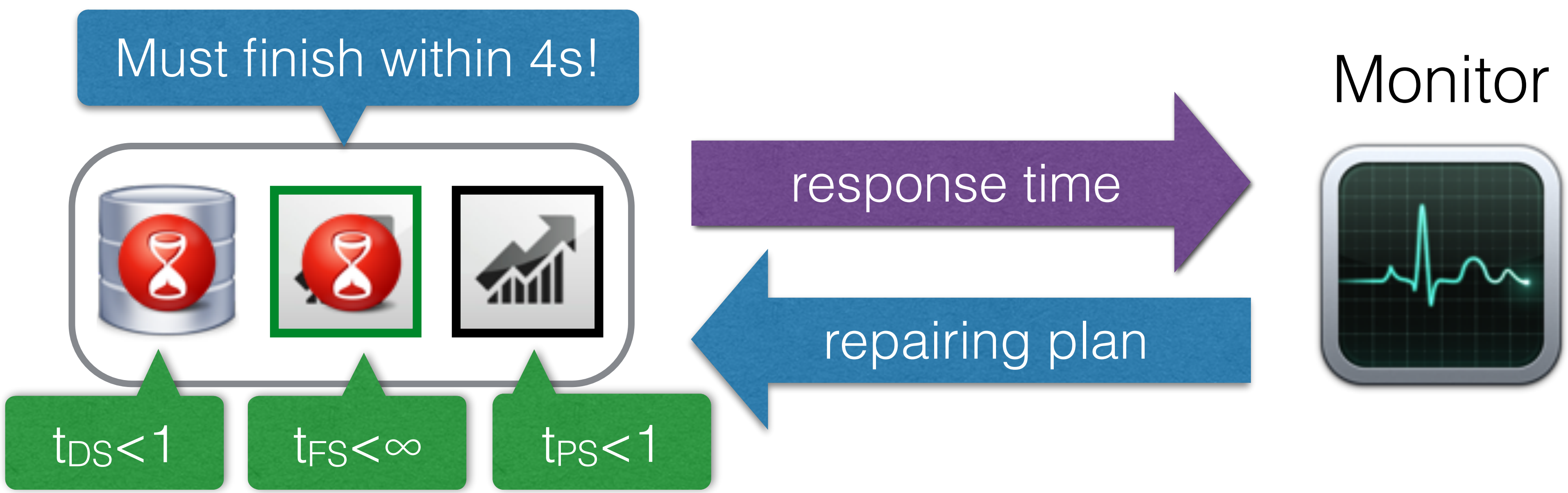


$\neg(0 \le t_{DS} \wedge 1 \le t_{FS} \wedge 1 \le t_{PS})$
$\wedge((0 \le t_{DS} \wedge 0 \le t_{FS} \wedge 0 \le t_{PS}) \Rightarrow t_{DS} \le 3)$
$\wedge((0 \le t_{DS} \wedge 0 \le t_{FS} \le 1 \wedge 0 \le t_{PS}) \Rightarrow t_{DS} + t_{FS} \le 3)$
$\wedge((0 \le t_{DS} \wedge 1 \le t_{FS} \wedge 0 \le t_{PS} \le 1) \Rightarrow t_{DS} + t_{PS} \le 2)$

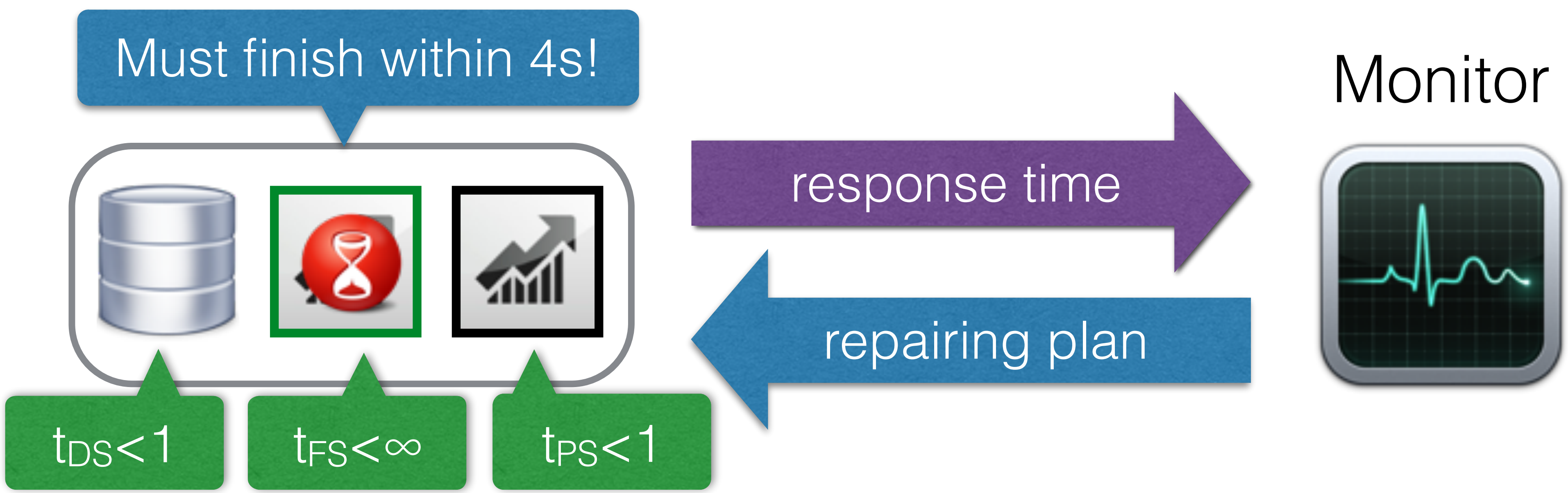
?

Have to replace both DS and FS.

uLTR for runtime adaptation and recovery

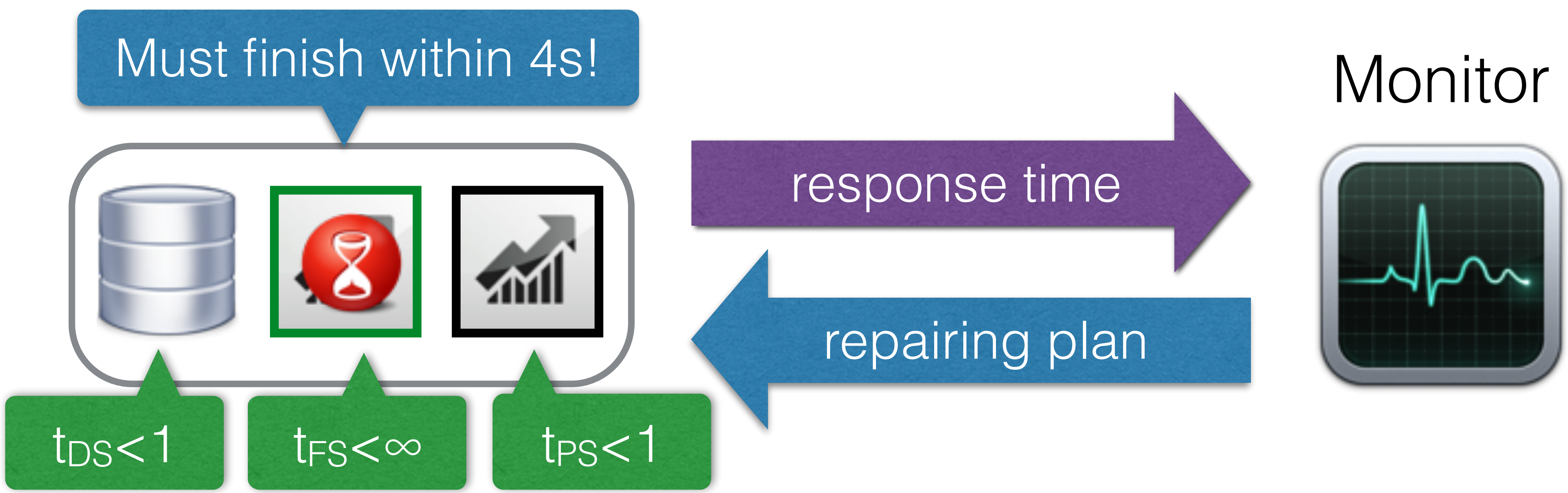


uLTR for runtime adaptation and recovery



Replacing DS is enough!

uLTR for runtime adaptation and recovery



Replacing DS is enough!

The "meaning" of LTR:
safe if one of t_{FS} and t_{PS} is less than 1.

uLTR for runtime adaptation and recovery

Experiments:

- *Use real service response time*
- *Simulate violations by adding uniform random delays to components*
- *Compare the length of recovery plans generated by LTR and uLTR*
- *In ~90% cases, uLTR discovers shorter repairs*

Limitations & Future Work

Limited evaluation

- *Need to look at other domains*

Proof of concept, not the silver bullet

- *Generalize the sampling algorithm: allow arbitrary hyper-rectangles*

Scalability issues:

- *Quantifier elimination*
- *Balance between precision and performance*

Checklist

☑ What is uLTR?

- *Component-independent under-approximated LTR*
- *Soundness: ensure timing safety*

☑ How to break up the monolithic constraint?

- *Compute uLTR from LTR*
- *Precision: preserve as many choices as possible*

☐ How can localized constraints support the management of timing requirements?

- *uLTR for component selection*
- *uLTR for runtime adaptation and recovery*

Checklist

What is uLTR?

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Questions?

Thank you!

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