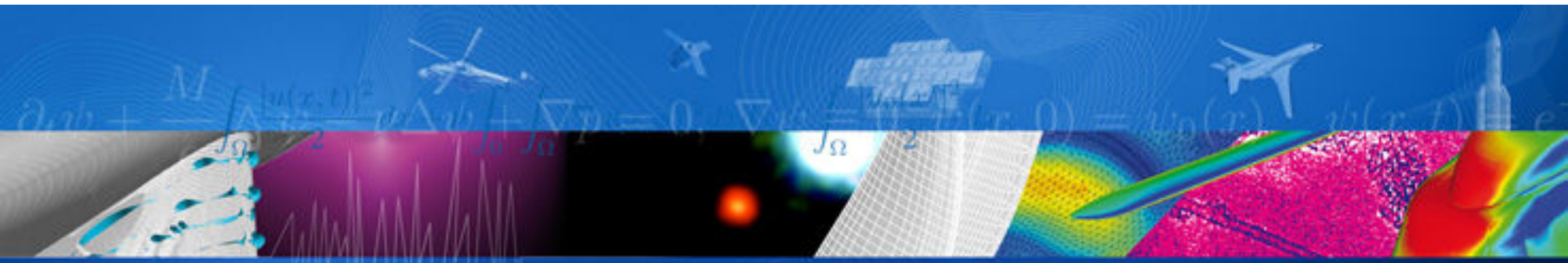


ONERA

THE FRENCH AEROSPACE LAB

retour sur innovation

www.onera.fr

Time-dependent Simple Temporal Networks

Cédric Pralet, Gérard Verfaillie

October 10th, 2012

ONERA
THE FRENCH AEROSPACE LAB

retour sur innovation

Overview

STN (Simple Temporal Networks) [DechterMeiriPearl91]

Framework for managing constraints of the form $y - x \geq c$, with c a constant
Several problems over STN **solvable in polytime**

Overview

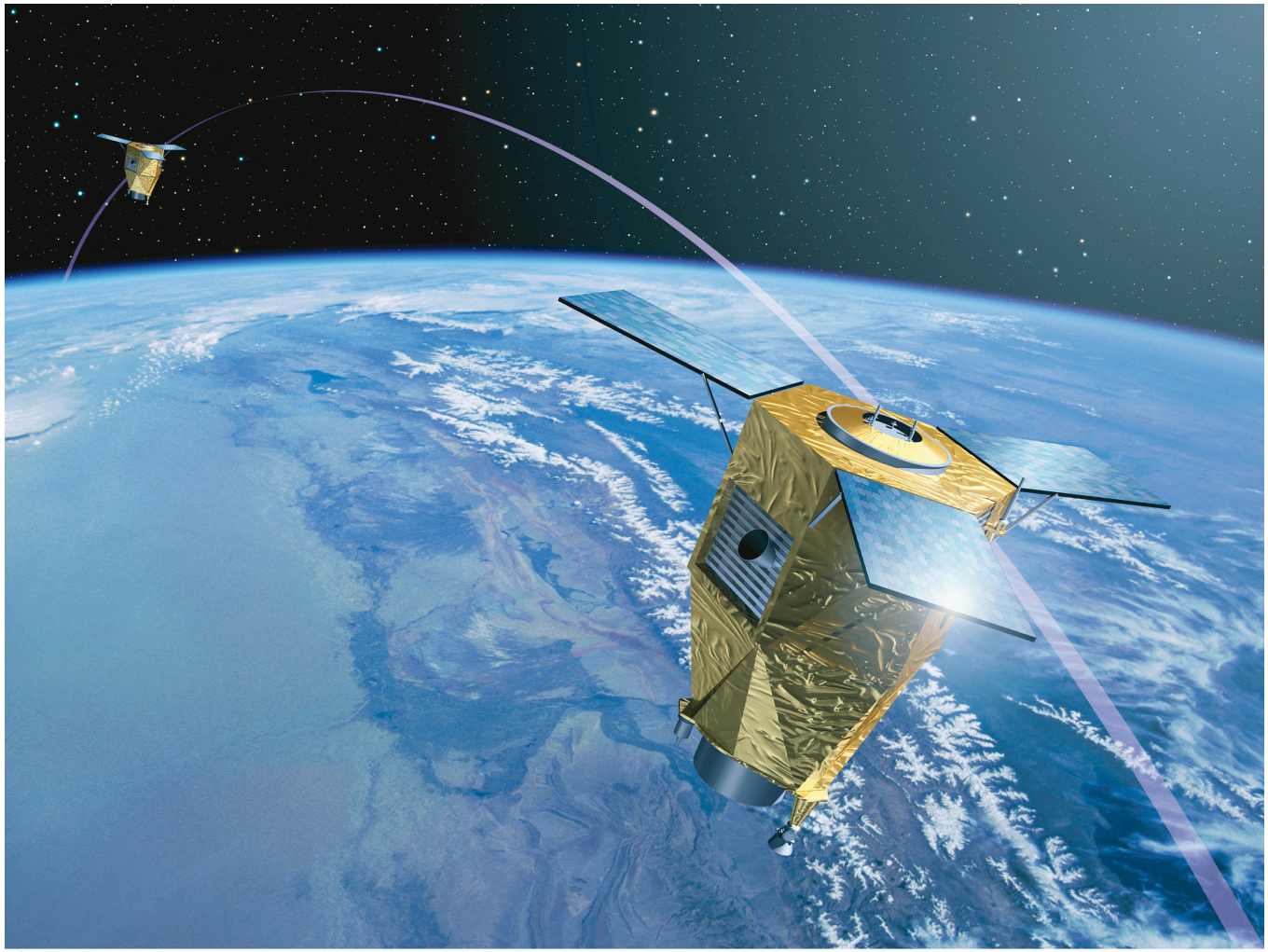
STN (Simple Temporal Networks) [DechterMeiriPearl91]

Framework for managing constraints of the form $y - x \geq c$, with c a constant
Several problems over STN **solvable in polytime**

Paper's contribution: **TSTN (Time-dependent Simple Temporal Networks)**

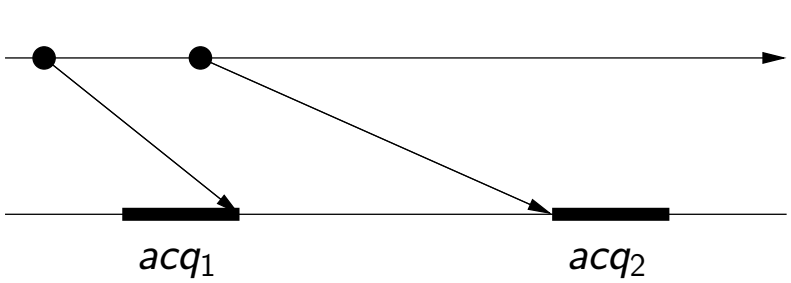
Framework for managing constraints of the form $y - x \geq dmin(x, y)$
(min distance between x and y depending on the time at which the transition from x to y occurs)

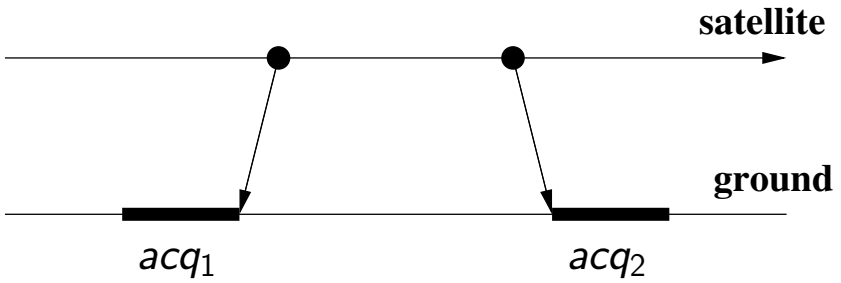
Motivation: agile satellites



Motivations for constraints $y - x \geq dmin(x, y)$

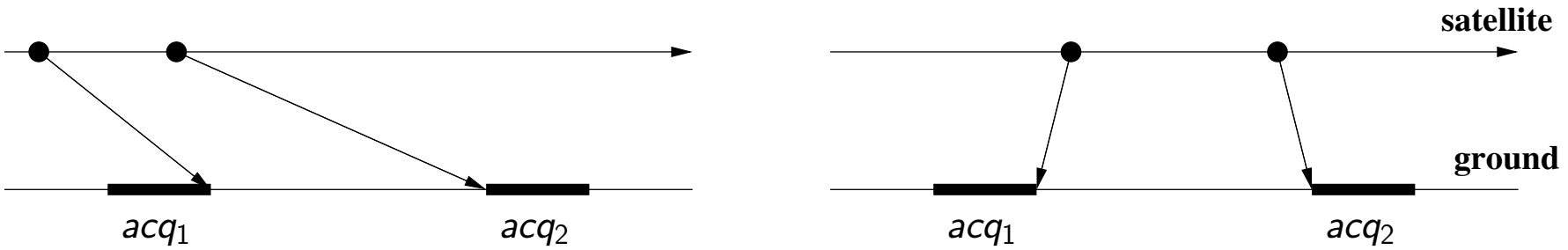
Modeling of **constraints for agile satellites**





Motivations for constraints $y - x \geq dmin(x, y)$

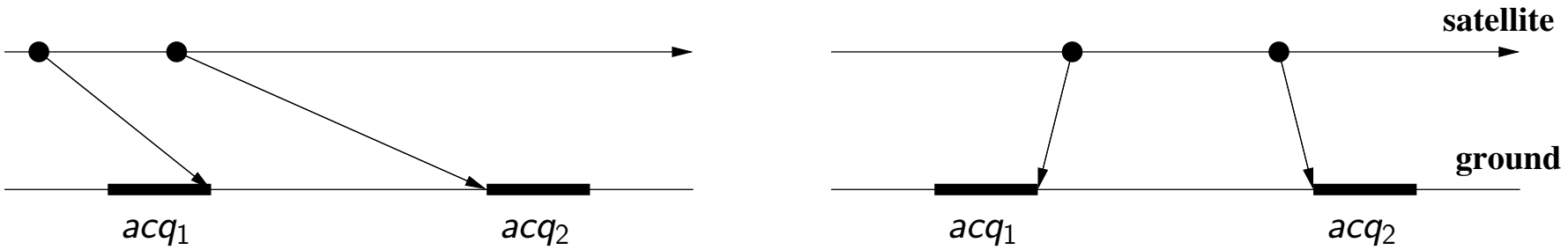
Modeling of **constraints for agile satellites**



$$sta_2 - end_1 \geq \underbrace{minAttTransTime(EndAtt_1(end_1), StaAtt_2(sta_2))}_{dmin(end_1, sta_2)}$$

Motivations for constraints $y - x \geq dmin(x, y)$

Modeling of **constraints for agile satellites**



$$sta_2 - end_1 \geq \underbrace{minAttTransTime(EndAtt_1(end_1), StaAtt_2(sta_2))}_{dmin(end_1, sta_2)}$$

Other problems covered:

- **time-dependent scheduling:** $y - x \geq p(x)$
  Example: logistics with traffic congestion
- **simple temporal problems:** $y - x \geq c$

Framework considered

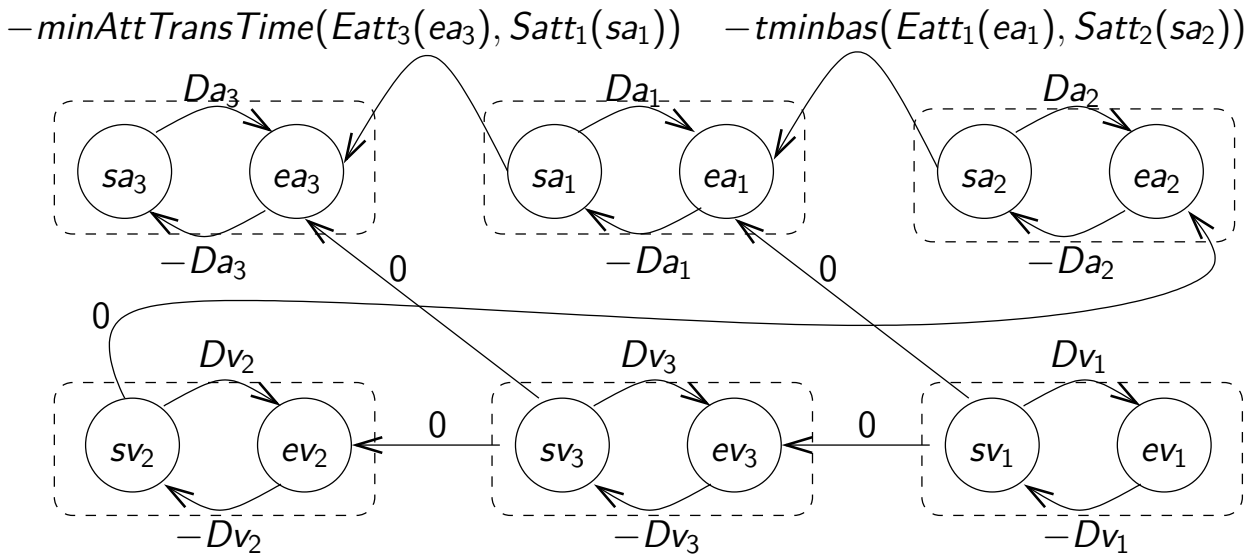
TSTN (Time-dependent Simple Temporal Network) = pair (V, C) with:

- V finite set of **variables** whose domain is an interval $[l, u] \subset \mathbb{R}$
- C finite set of constraints of the form $c : y - x \geq dmin(x, y)$ with $dmin : \mathbf{D}(x) \times \mathbf{D}(y) \rightarrow \mathbb{R}$

TSTN (Time-dependent Simple Temporal Network) = pair (V, C) with:

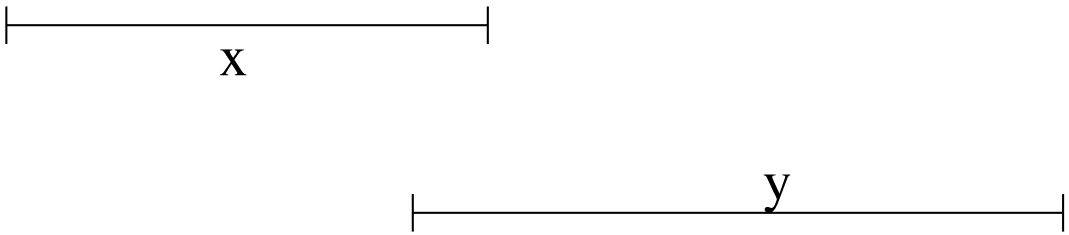
- V finite set of **variables** whose domain is an interval $[l, u] \subset \mathbb{R}$
- C finite set of constraints of the form $c : y - x \geq dmin(x, y)$ with $dmin : \mathbf{D}(x) \times \mathbf{D}(y) \to \mathbb{R}$

As in STN, notion of **distance graph** (one arc $y \to x$ weighted by $-dmin(x, y)$ per constraint $y - x \geq dmin(x, y)$)



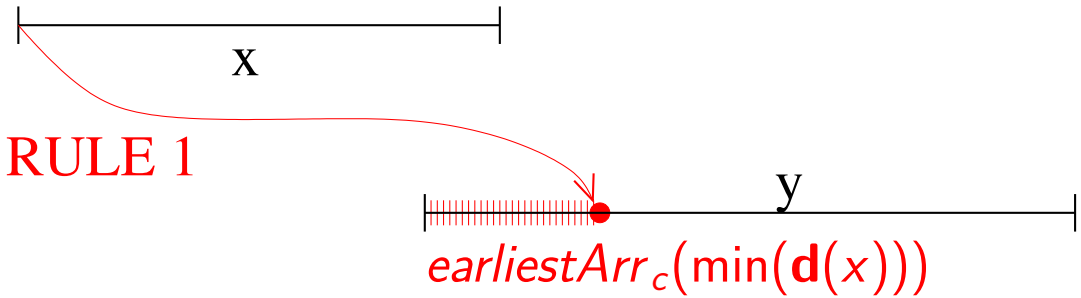
Arc-consistency for $c : y - x \geq dmin(x, y)$

Propagation rules enforcing **Bound-AC (BAC)**:



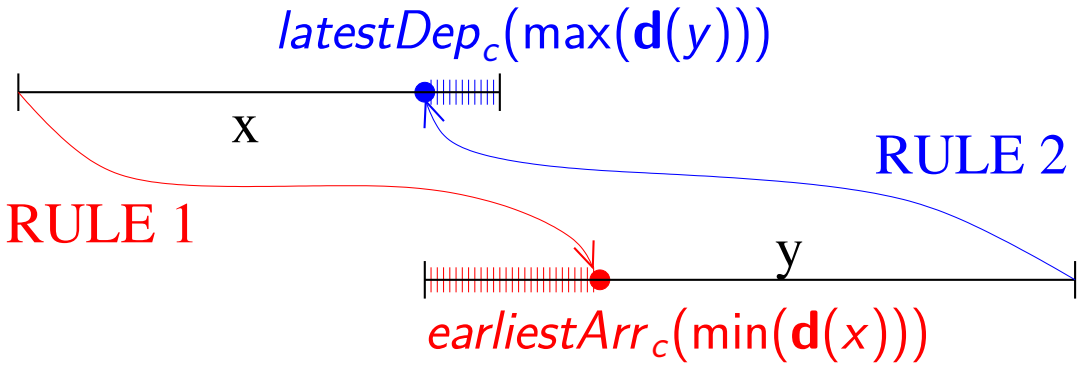
Arc-consistency for $c : y - x \geq dmin(x, y)$

Propagation rules enforcing **Bound-AC (BAC)**:



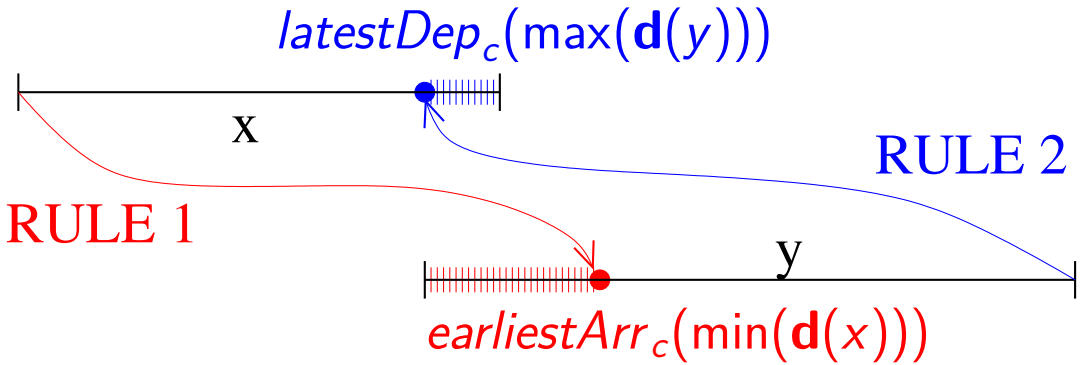
Arc-consistency for $c : y - x \geq dmin(x, y)$

Propagation rules enforcing **Bound-AC (BAC)**:



Arc-consistency for $c : y - x \geq dmin(x, y)$

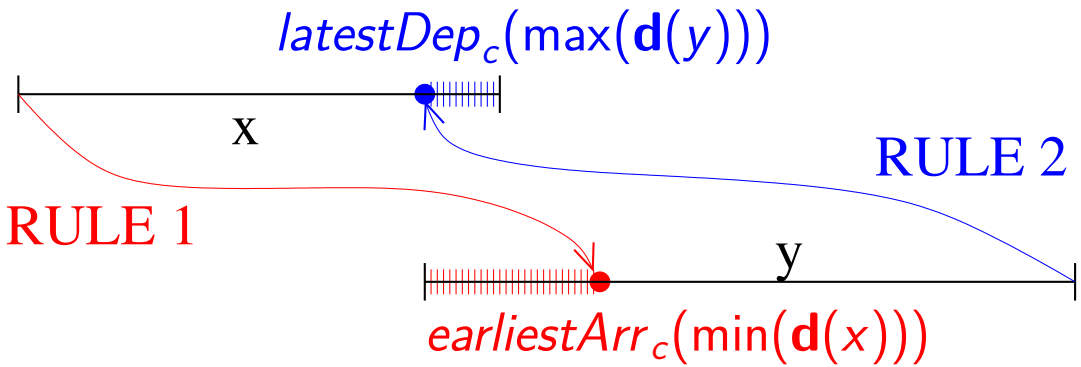
Propagation rules enforcing **Bound-AC (BAC)**:



earliestArr / *latestDep* computed using an **iterative approximate method** in the general case (no analytical definition)

Arc-consistency for $c : y - x \geq dmin(x, y)$

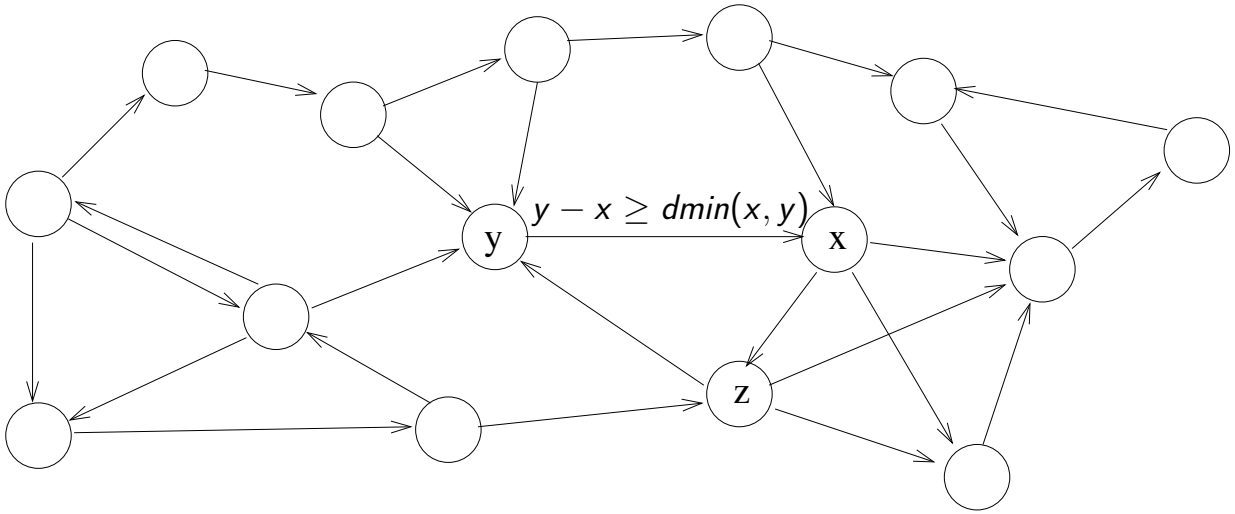
Propagation rules enforcing **Bound-AC (BAC)**:



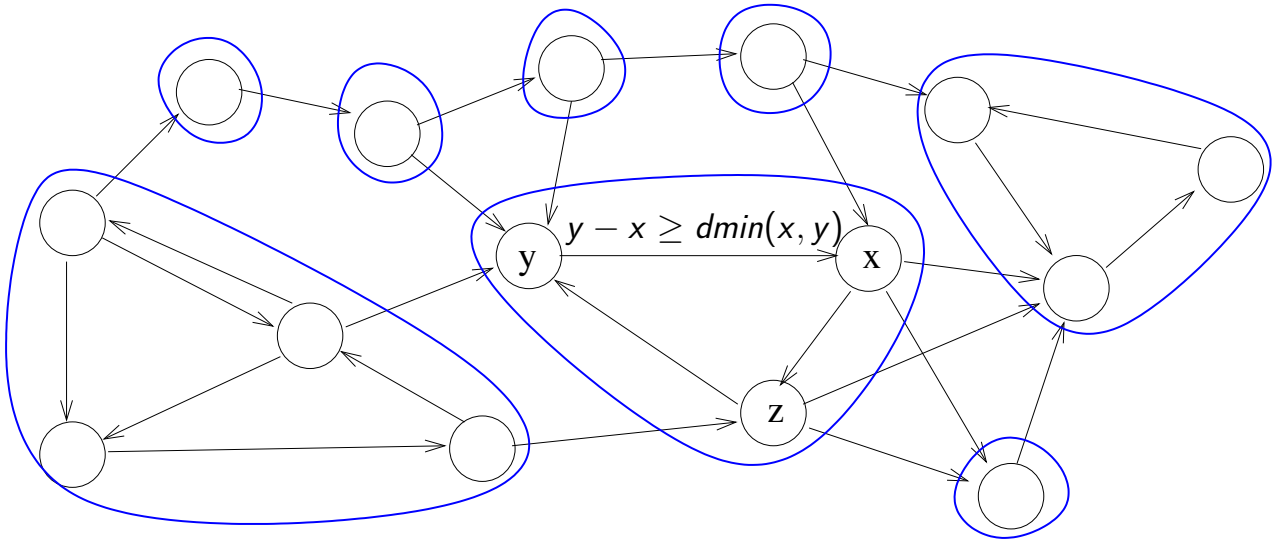
earliestArr / *latestDep* computed using an **iterative approximate method** in the general case (no analytical definition)

For agile satellites, coupling with a **continuous control optimization library**

TSTN algorithms

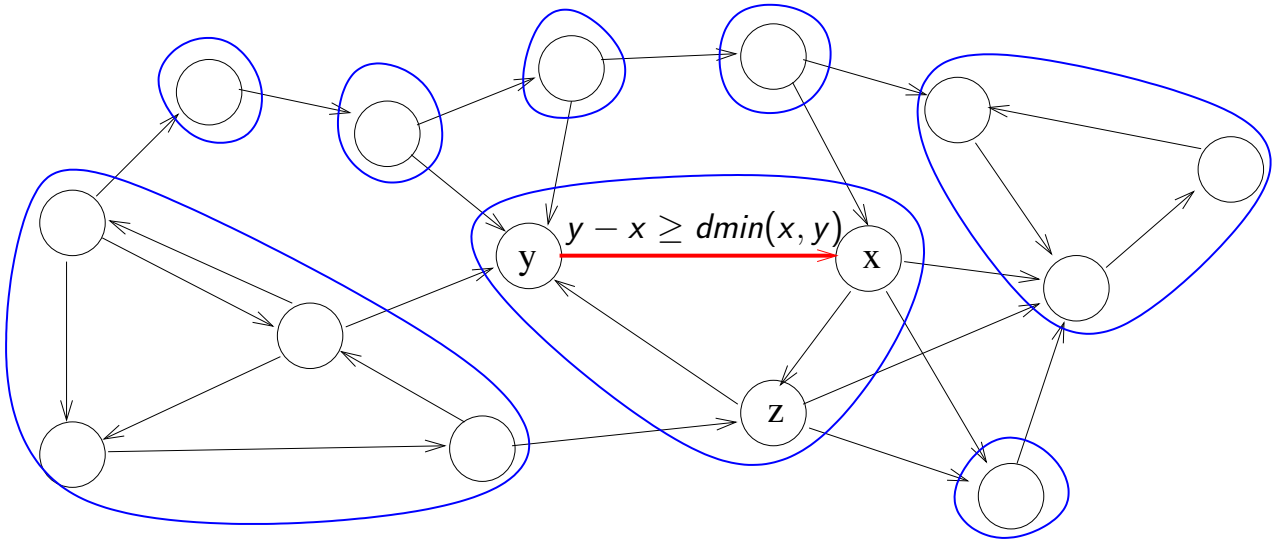


TSTN algorithms



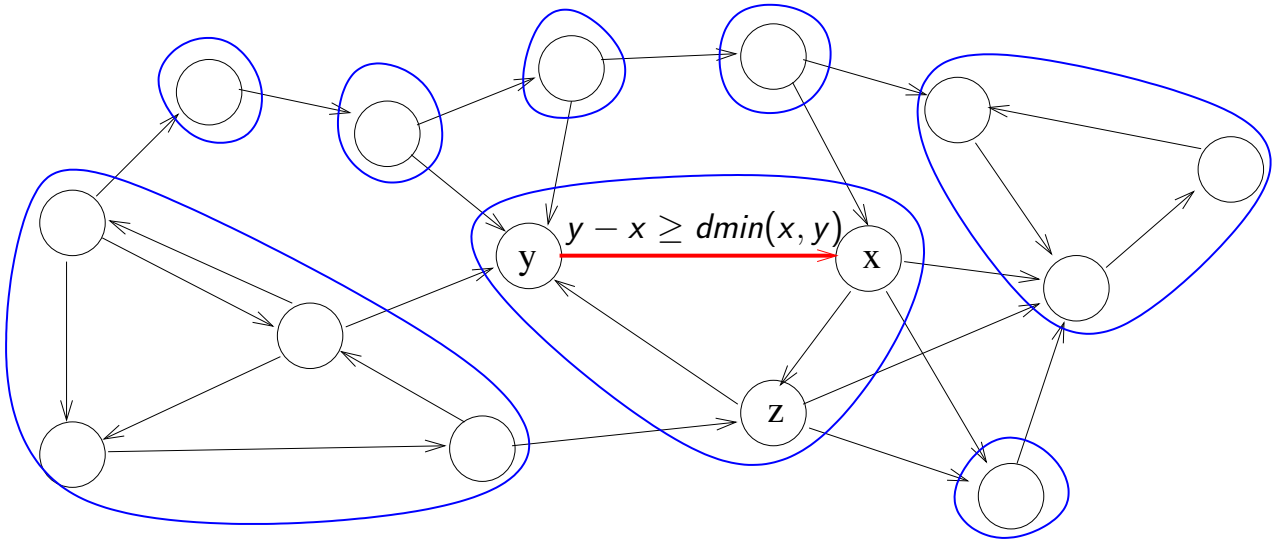
1. **Constraint revision ordering** following a topological order of Strongly Connected Components (SCCs) of the distance graph

TSTN algorithms



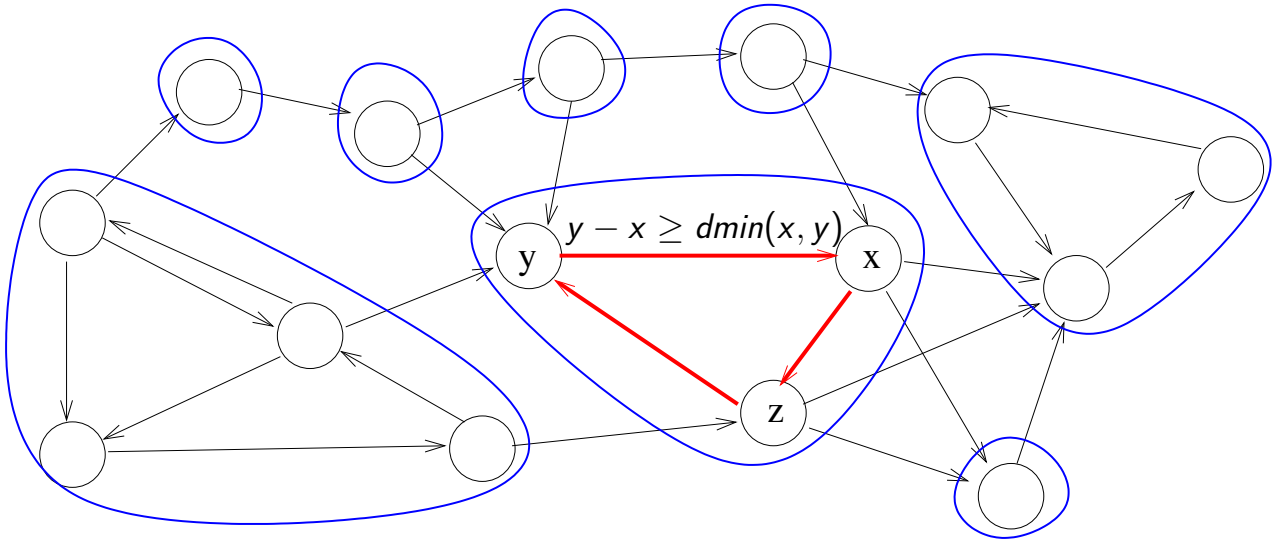
1. **Constraint revision ordering** following a topological order of Strongly Connected Components (SCCs) of the distance graph
2. Recording of **propagation chains**

TSTN algorithms



1. **Constraint revision ordering** following a topological order of Strongly Connected Components (SCCs) of the distance graph
2. Recording of **propagation chains**
3. Incremental constraint additions **and removals** (used by local search algorithms on top of the STN/TSTN tool)

TSTN algorithms



1. **Constraint revision ordering** following a topological order of Strongly Connected Components (SCCs) of the distance graph
2. Recording of **propagation chains**
3. Incremental constraint additions **and removals** (used by local search algorithms on top of the STN/TSTN tool)
4. Inconsistency detection based on **propagation cycle detection** (difference with STN: inconsistency $\leftrightarrow$ existence of a propagation cycle)

TSTN algorithms

Algorithm establishing BAC over TSTN in $O(|V||C|)$ **constraint revisions (under some conditions)**

Theoretical results

Prop. 1

If all constraints are BAC, then the **earliest** and **latest** schedules are **solutions of the TSTN**

Theoretical results

Prop. 1

If all constraints are BAC, then the **earliest** and **latest** schedules are **solutions of the TSTN**

Prop. 2

If $c : y - x \geq dmin(x, y)$ **delay-monotonic** (see precise definition in the paper), then **BAC** $\leftrightarrow$ **AC**

Theoretical results

Prop. 1

If all constraints are BAC, then the **earliest** and **latest** schedules are **solutions of the TSTN**

Prop. 2

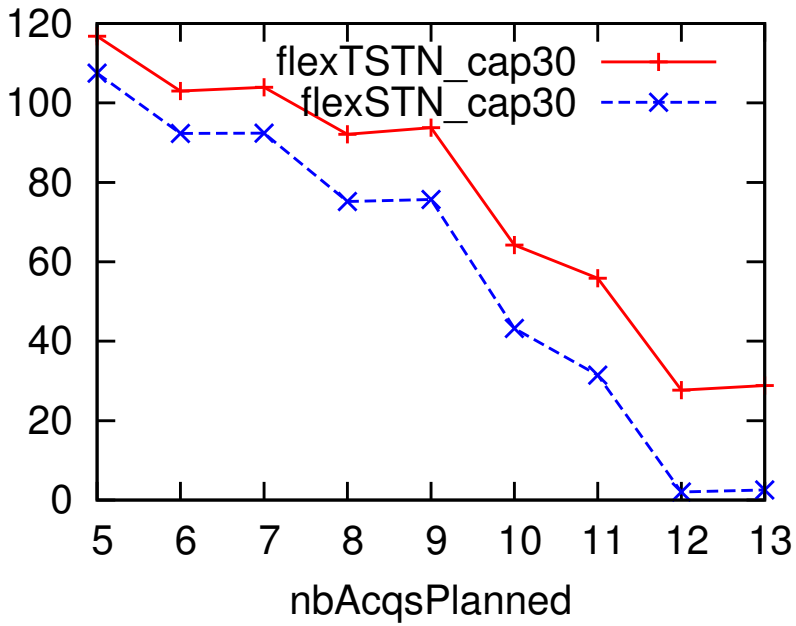
If $c : y - x \geq dmin(x, y)$ **delay-monotonic** (see precise definition in the paper), then **BAC $\leftrightarrow$ AC**

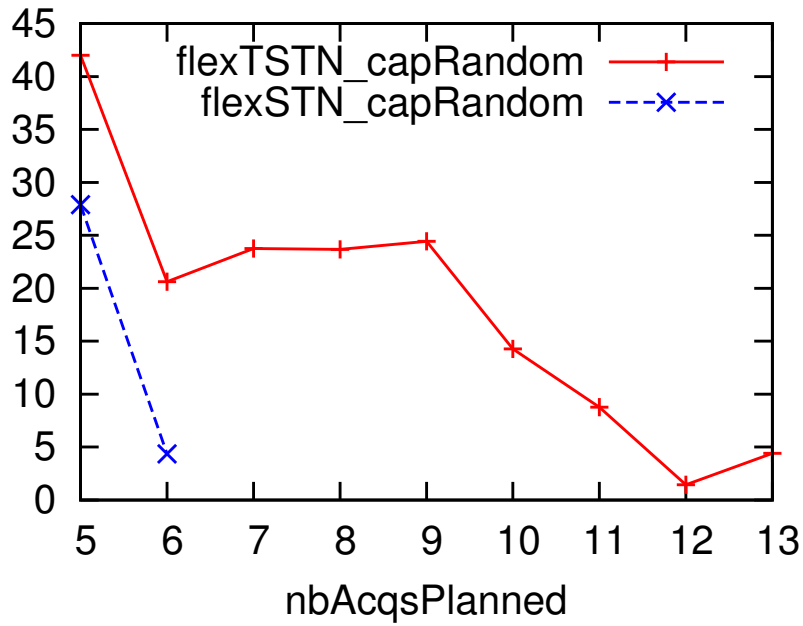
Prop. 3

Contrarily to STN, even if all constraints are BAC (or AC), values remaining in the domains are **not necessarily globally consistent**

Globally consistency OK **if** delay-monotonicity and only simple temporal constraints ($dmin(x, y) = c$) in cycles of the distance graph

Practical results on agile satellites





Result: with TSTN, **more acquisitions** and **more flexibility** on acquisition plans than with STN based on constant upper bounds on transition times

More global view...

TSTN = **temporal layer** of a constraint-based local search solver developed for handling space missions

Other aspects taken into account (not presented here):

- constraints on **resources** (energy, memory, temperature...)
- several optimization **criteria**
- **operational** constraints