UNIVERSITÀ di VERONA
Dep. of Computer Science

ICAPS 2020

Dynamic Controllability and (J,K)-Resiliency of Generalized Constraint Networks with Uncertainty

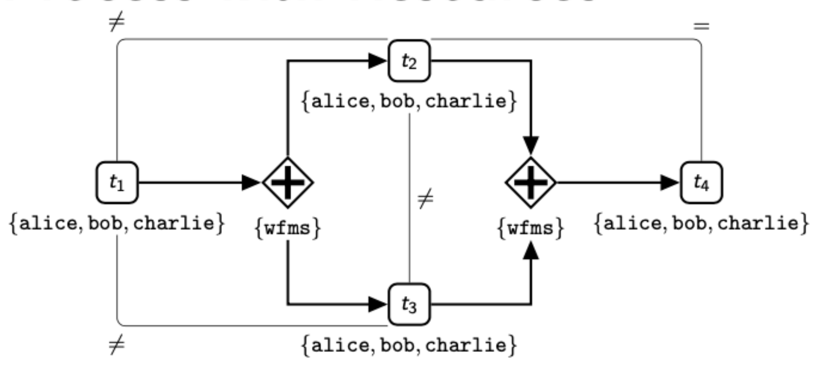
Matteo Zavatteri, Romeo Rizzi, Tiziano Villa
{matteo.zavatteri,romeo.rizzi,tiziano.villa}@univr.it

Aims of the Work

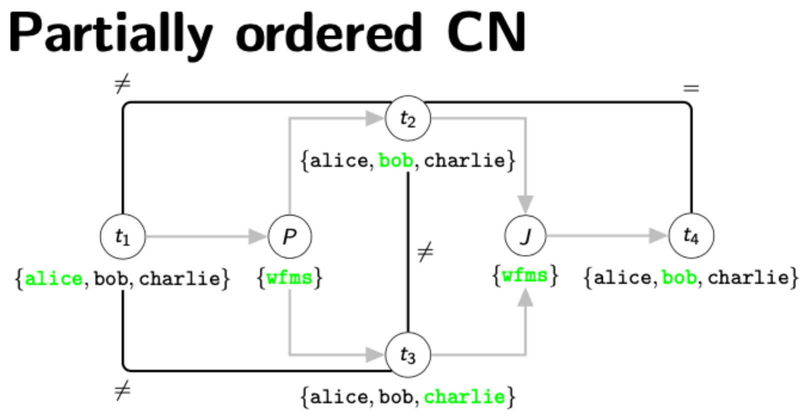
1. **Handling resource allocation under uncertainty in a qualitative time domain.**
2. **Exploring resiliency (=sudden absence of resources) on top of dynamic controllability.**
3. **Estimating complexity of such a kind of planning.**

Constraint Networks for Resource Allocation

Process with Resources

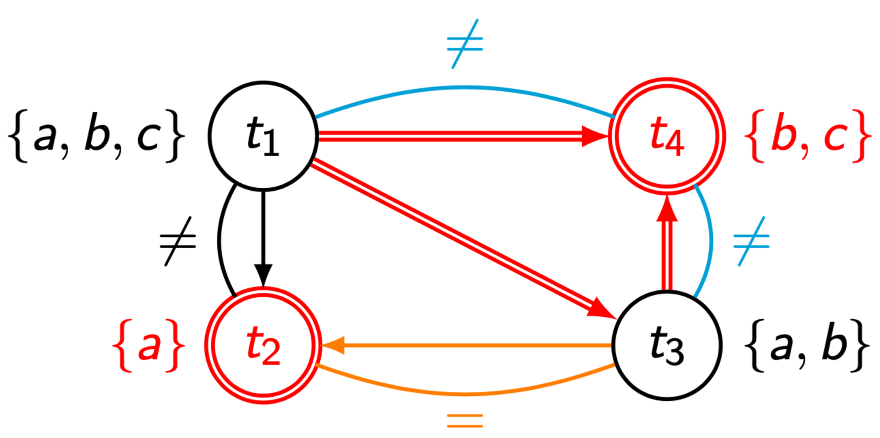


Partially ordered CN



How to get a plan:
1) Compute a topological sort (polynomial-time step)
2) Solve the constraint network (NP-hard step)

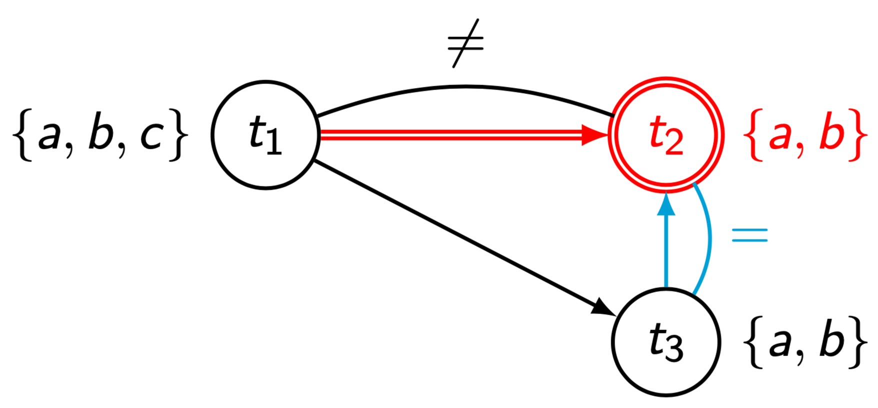
Generalized CNs with Uncertainty



In words:
1) Variables with controllable and uncontrollable value assignment (double circles)
2) Variables with uncontrollable picking and (acyclic) activation constraints (double arrows)
3) Constraints language: arbitrary boolean formula over relational and partial order constraints.
4) Allow for defining problems as 2-player games Controller-Nature.
5) Qualitative time approach.

What we do:
- we execute (=pick *then* assign values) to variables one at a time.
- t_2 and t_4 have uncontrollable value assignments.
- t_3 and t_4 have uncontrollable pickings (=once active they can be executed ``anytime'').
- $(t_1 < t_2) \wedge (t_1 \neq t_2) \wedge (t_1 \neq t_4 \vee t_3 \neq t_4) \wedge (t_3 < t_2 \vee t_2 = t_3)$.

Dynamic Controllability

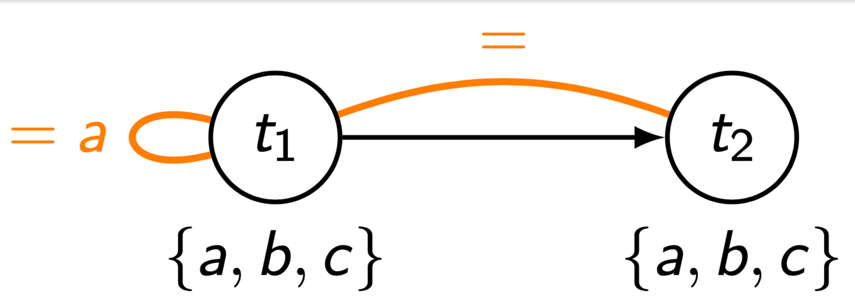


Dynamically Controllable.

In words:
1) Round-based Game between Controller and Nature.
2) At every round a variable is *first* picked, *then* assigned a value.
3) Both Controller and Nature can pick and/or assign (=4 possible cases).
4) Nature has priority over Controller when picking.
5) Dynamic controllability = Winning strategy for Controller.
6) Uncontrollability = Winning strategy for Nature.

Controller's Winning Strategy:
1) Controller picks t_1 and assigns *c* to it (t_2 is now ready for picking)
2) If Nature doesn't pick t_2,
   2.1) Controller picks t_3 and assigns any value to it.
   2.2) Nature picks t_2 and assigns a value to it
3) If Nature picks t_2, she also assigns a value to it.
4) Controller picks t_3 and assigns to it the same value assigned to t_2.

(J,K)-Decremental Resiliency



Not (2,2)-decrementally resilient.

In words:
1) On top of dynamic controllability.
2) *J* and *K* are natural numbers
3) For maximum *J* rounds Nature *strikes* by r removing *overall* up to *K* values
4) After that, Controller and Nature pick and assign values to variables (among those remained).
5) We still look for a winning strategy for Controller.
6) *J* depends on *K* (*i.e., J ≤ K*)

Nature's Winning Strategy:
1) Nature removes a at Round 1
2) Controller picks t_1 and assigns *b* or *c* to it at Round 1
3) Nature removes the value that Controller assigned to t_2 at Round 2.
4) Controller cannot assign the same value to t_2 at Round 2 (i.e., loses the game).

(J,K)-Dynamic Resiliency

(1, 1)-**dynamically resilient**

In words:
1) Like decremental, but with value re-entering at the end of round.
2) For maximum *J* times, at the start of every round, Nature strikes by removing up to *K* values.
3) After that, Controller and Nature pick and assign values to variables (among those remained).
4) Before the next round begins, all removed values become available again.
5) J is independent from K.

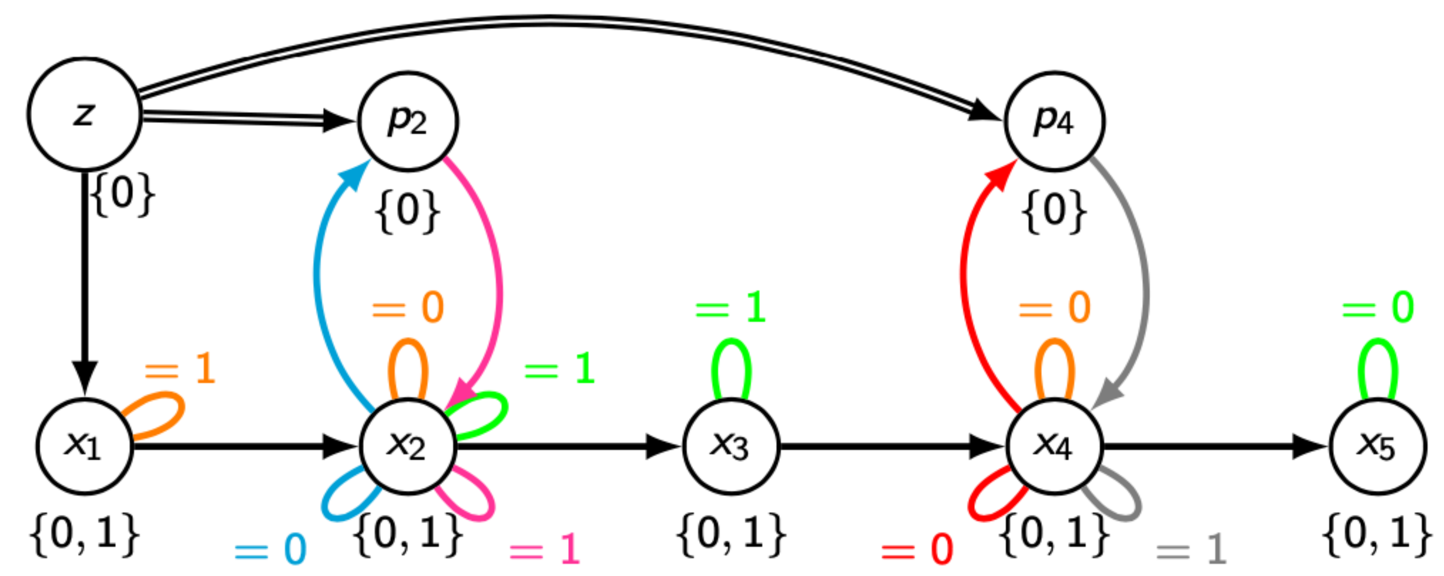
Controller's Winning Strategy:
1) If Nature removes a at round 1,
   1.1) Controller picks t2 and assigns b to it.
   1.2) Controller picks t1 and assigns a to it
2) If Nature doesn't remove a at Round 1.
   2.1) Controller picks t1 and assigns a to it
   2.2) Controller picks t2 and assigns any value to it among those available.

PSPACE-completeness

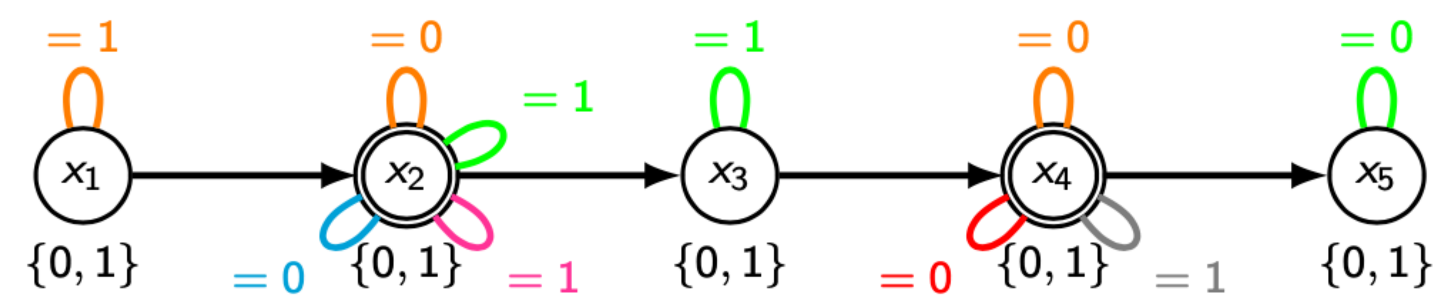
Dynamic Controllability is PSPACE-complete

$$\exists x_1 \forall x_2 \exists x_3 \forall x_4 \exists x_5 (x_1 \vee \neg x_2 \vee \neg x_4) \wedge (x_2 \vee x_3 \vee \neg x_5)$$

Uncontrollable pickings only



Uncontrollable variable assignments only



- ***Hardness*: reduction from true quantified boolean formula**
- ***Membership*: AND/OR search tree with depth bounded by a polynomial in the number of variables.**

(J,K)-Decremental and (J,K)-Dynamic Resiliency are PSPACE-complete as well.

Future Work

Development of strategy synthesis algorithms

References

Matteo Zavatteri, Romeo Rizzi, and Tiziano Villa. Dynamic Controllability and (J, K)- Resiliency in Generalized Constraint Networks with Uncertainty. In Proceedings of the Thirtieth International Conference on Automated Planning and Scheduling, ICAPS 2020, pages 314–322. AAAI Press, 2020.