COMPLEXITY OF REPAIR FOR SIMPLE TEMPORAL NETWORKS WITH UNCERTAINTY

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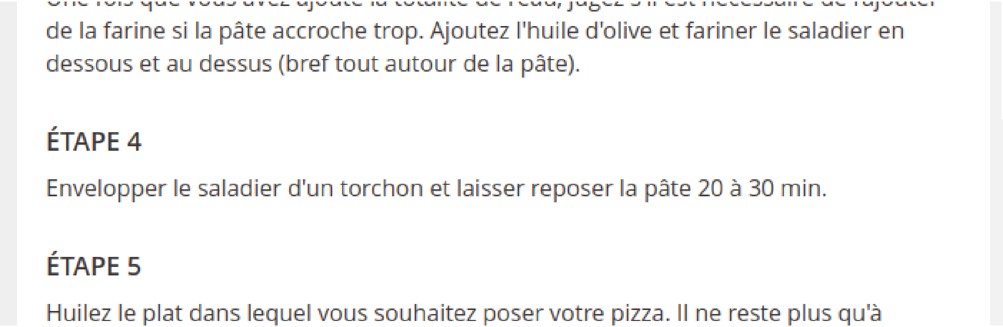
Temporal Networks



Une fois que vous avez ajouté la totalité de l'eau, jugez s'il est nécessaire de rajouter de la farine si la pâte accroche trop. Ajoutez l'huile d'olive et fariner le saladier en dessous et au dessus (bref tout autour de la pâte).

ÉTAPE 4

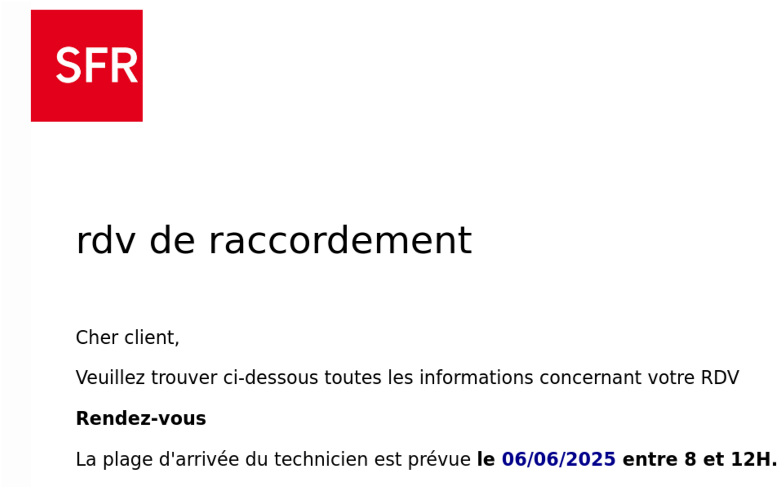
Envelopper le saladier d'un torchon et laisser reposer la pâte 20 à 30 min.

ÉTAPE 5

Huilez le plat dans lequel vous souhaitez poser votre pizza. Il ne reste plus qu'à

(source: `https://www.marmiton.org/recettes/recette_pate-a-pizza-inratable_31623.aspx`)

Uncertainty



SFR

rdv de raccordement

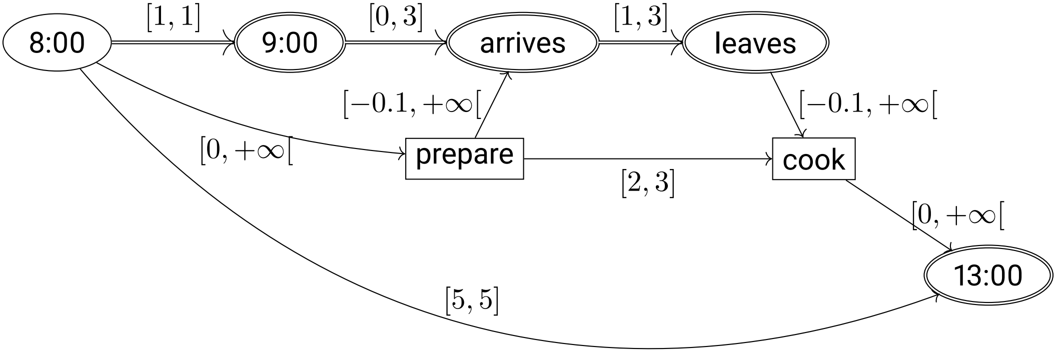
Cher client,

Veuillez trouver ci-dessous toutes les informations concernant votre RDV

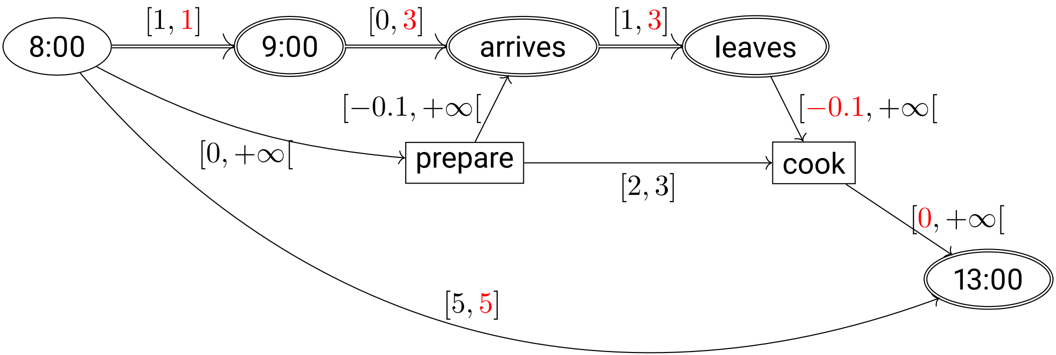
Rendez-vous

La plage d'arrivée du technicien est prévue **le 06/06/2025 entre 8 et 12H.**

STNUs

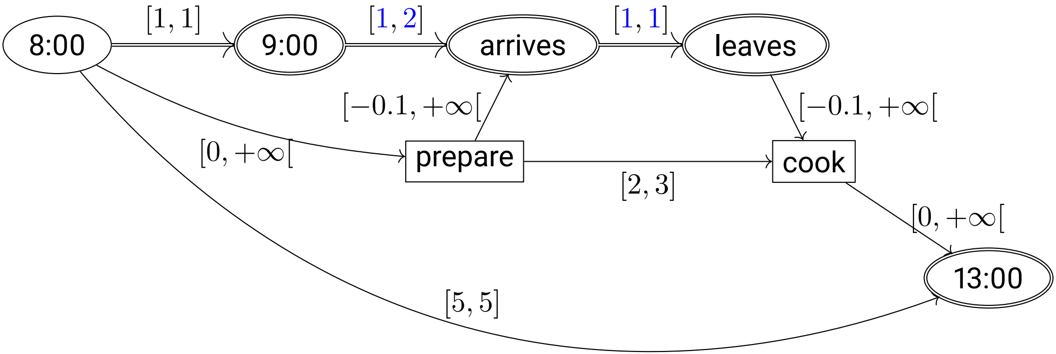

8:00
$[1, 1]$
9:00
$[0, 3]$
arrives
$[1, 3]$
leaves
$[-0.1, +\infty[$
$[-0.1, +\infty[$
$[0, +\infty[$
prepare
$[2, 3]$
cook
$[0, +\infty[$
13:00
$[5, 5]$

Controllability



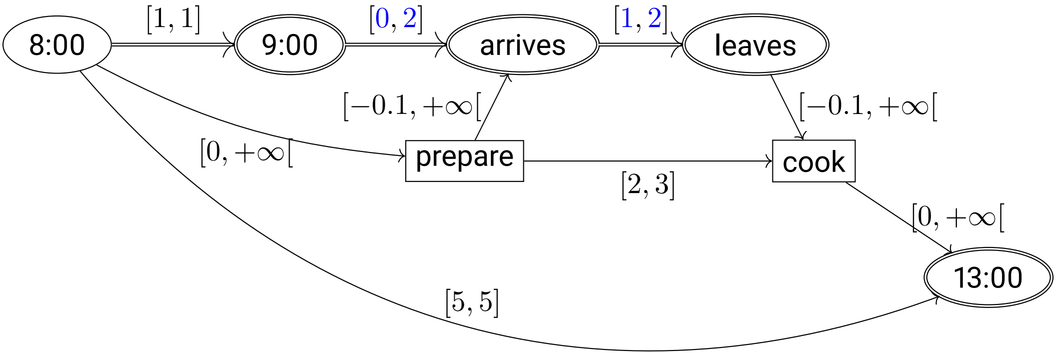
Not controllable

Repair



Controllable: prepare at 10:00, cook at 12:00

Another Repair



Controllable: prepare at earliest(arrival + 0.1, 11:00), cook 2 hours later

This talk

Complexity of repairing STNUs

What for?

- contingencies may be controllable by other agents
  repairing = negotiating
  call SFR
- contingencies can be shrinked by spending more resources
  give strong coffee to technician
  more fuel for driving faster

Outline

1. STNUs and Controllability

2. Repairing STNUs

3. Conclusion

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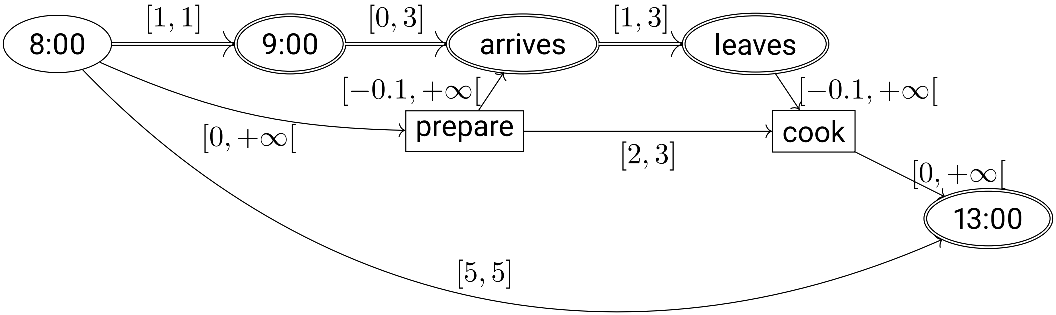
STNUs

- Controllable and uncontrollable timepoints
- Constraints (requirements) between timepoints
- Known bounds on duration of contingencies



Schedules

Schedule $\sim$ plan:

- durations of contingencies → dates for controllable timepoints
- additional restrictions depending on type
- valid if satisfies requirement constraints

Strong Schedule

A single, valid schedule independent of actual durations of contingencies

prepare at 10:00, cook at 12:00

- execution without (the need for) observing uncontrollable timepoints
- conformant planning
- controllable timepoints can be scheduled ahead of execution

Arrive at same time as friend $\pm$ *5 minutes, whatever happens to friend*

Weak Schedule

No restriction: dependent of actual durations of all contingencies

if arrives at 9:00 and leaves at 12:00, prepare at 9:00, cook at 12:00
if arrives at 9:00 and leaves at 11:00, prepare at 8:00, cook at 11:00
etc.

- execution with knowledge of duration of all contingencies (even future)
- fully observable nondeterministic planning / MDPs

Ensure production feasible tomorrow, orders will arrive tonight

Inbetween: Dynamic Schedule

A schedule dependent of effective durations already observed

prepare at earliest(arrival + 0.1, 11:00), cook 2 hours later

- scheduling for all contingencies, reactive execution
- contingent planning / POMDPs

Take 17:59 train if tram arrived on time, otherwise take 18:59

Controllability, Formally

Given STNU with ctl timepoints $c_1, \ldots, c_n$ and contingencies $[\ell_1, u_1], \ldots, [\ell_k, u_k]$

Schedule:

- mapping $\delta : [\ell_1, u_1] \times \cdots \times [\ell_k, u_k] \times \{1, \ldots, \} \to \mathbb{R}$
- $\delta(\vec{\omega}, i) = t$: “$c_i$ scheduled at t if durations as in $\vec{\omega}$”
- valid if satisfies all constraints

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Restrictions:

- strong: $\forall i \forall \vec{\omega}, \vec{\omega}' : \delta(\vec{\omega}, i) = \delta(\vec{\omega}', i)$
- weak: no restriction
- dynamic: $\forall i \forall \vec{\omega}, \vec{\omega}' : \Big(\delta(\vec{\omega}, i) = t \wedge \text{Obs}(t \mid \delta, \vec{\omega}) = \text{Obs}(t \mid \delta, \vec{\omega}')\Big) \Rightarrow \delta(\vec{\omega}', i) = t$

STNU is X-controllable if $\exists$ valid schedule meeting restriction X

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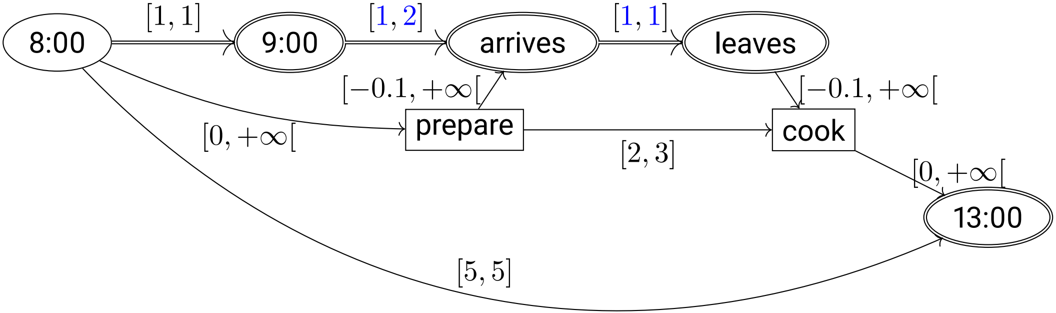
Repairs



Formally, given S not X-controllable, repair S':

- same (cont. and uncont.) timepoints and same requirements as S
- for all contingencies: $[\ell', u'] \subseteq [\ell, u]$ (contingency is shrinked)
- X-controllable

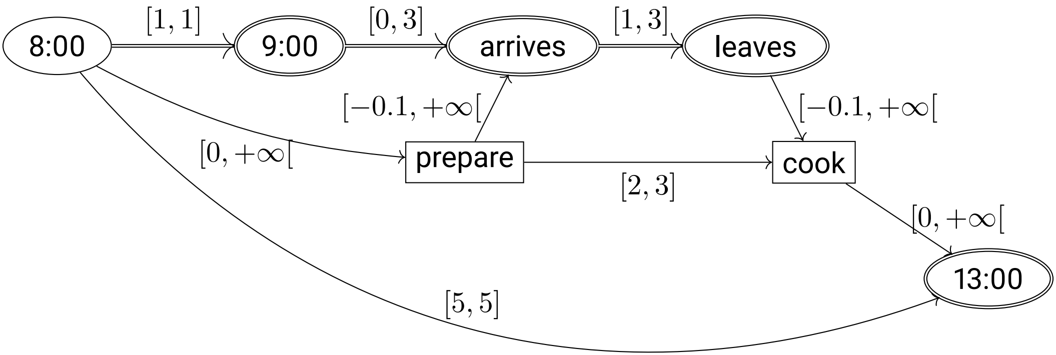
Restrictions on Repairs

- No restriction
- Only given contingencies can be shrinked (“partial”)
- Given b, sum of shrinkings $\leq b$ (“b-budget”)
- Given k, fewer than k contingencies shrinked (“k-constraint”)

12 computational problems:

$$\{\text{strong, weak, dynamic}\} \times \{\text{repair, partial, } b\text{-budget, } k\text{-constraint}\}$$

Example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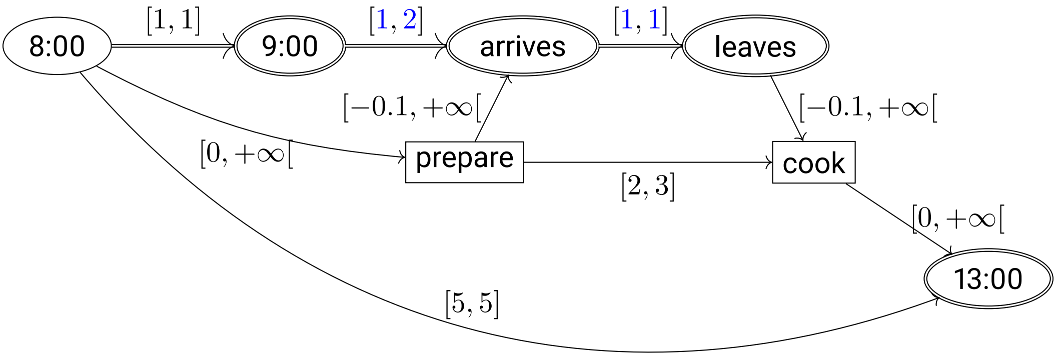
Example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$[2, 3]$
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$[5, 5]$

First Thoughts

Complexity of controllability:

- strong: polytime (lin. prog.)
- weak: coNP-complete ($\forall \vec{\omega} : \ldots$)
- dynamic: polytime (not obvious)

Repair: $\exists S' : \ldots$ and S' X-controllable

- bet on one level higher in PH than controllability

Lemmas

Singleton repairs:

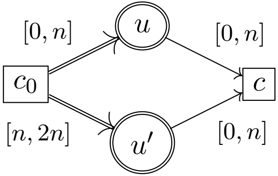
- each shrinking of the form: $[\ell, u]$ to $[v, v]$
- $\exists$ repair $\Leftrightarrow$ $\exists$ singleton repair: for unrest., partial, k-constraints

Wrt controllability:

- controllable = partial repair with none allowed
- controllable = 0-budget repair
- controllable = 0-constraint repair
- hence all at least as hard

Gadget for Hardness

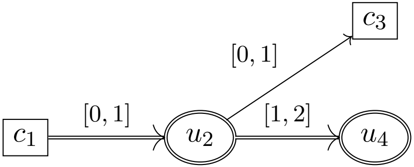
k-constraint can force $\{0,1\}$-choice:

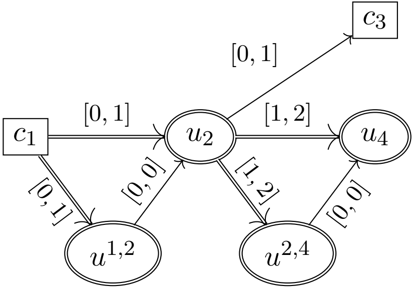


- Repair top to $[n]$ and schedule c at $2n$, or
- Repair bottom to $[n]$ and schedule c at n

Partial vs Budget

Partial reduces to k-budget:





Repairing given constraint iff repairing using budget 2

Results (1/2)

k-constraint always hard (using gadget):

- strong, dynamic: NP-complete (from subset-sum)
- weak: Σ_2P-complete (from $\exists\forall$-3-uncol)
- note: membership not obvious

Results (1/2)

k-constraint always hard (using gadget):

- strong, dynamic: NP-complete (from subset-sum)
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- note: membership not obvious

All unconstrained repairs easy:

- amounts to $\exists$ singleton repair: X-controllable
- hence to controlling contingencies
- hence STN (LP)

Results (2/2)

Strong:

- controllability: $\exists c_1, \ldots, c_n$: linear constraints (LP)
- repair, partial repair: $\exists$ singleton repairs: controllable (still LP)
- b-budget repair: $\exists$ singleton repairs: controllable and cost $\leq b$ (still LP)
- k-constraint repair: NP-complete

Results (2/2)

Strong:

- controllability: $\exists c_1, \ldots, c_n$: linear constraints (LP)
- repair, partial repair: $\exists$ singleton repairs: controllable (still LP)
- b-budget repair: $\exists$ singleton repairs: controllable and cost $\leq b$ (still LP)
- k-constraint repair: NP-complete

Weak:

- controllability: coNP-complete
- repair: polytime
- partial, b-budget repair: coNP-hard (from controllability)
- partial, b-budget repair: in coNP (nontrivial)
- k-constraint repair: Σ_2P-complete

Dynamic Repairs

Known:

- controllability: polytime
- repair: polytime
- partial repair, b-budget repair: in NP (from literature)
- k-constraint repair: Σ_2P-complete

Dynamic Repairs

Known:

- controllability: polytime
- repair: polytime
- partial repair, b-budget repair: in NP (from literature)
- k-constraint repair: Σ_2P-complete

Ongoing work:

- partial, b-budget repair: polytime or NP-complete?
- directions: is the space of repairs convex?
- difficulty: earliest(arrival + 0.1, 11:00)

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Summary and Future Work

Complexity of repairing STNUs:

- scheduling problems with constraints and uncertainty
- repairing by negotiating in MA setting
- repairing by spending more resources

Future work:

- settle complexity for dynamic
- generalize results (k, b-budget, etc.)
- dynamic MA schedules...