Abstractions for Analyzing Decision-Based Process Models

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Modeling critical processes

- Processes & workflows can be safety-critical
  - E.g. healthcare processes
    - Medical errors: 98,000 deaths each year in the US, over 1 million of non-lethal injuries
    - Major cause: complex coordination of clinical tasks
- Critical processes need *models* for analysis, error anticipation and enactment [Clarke, ICSE'08]
- Building adequate, complete, consistent process models is difficult

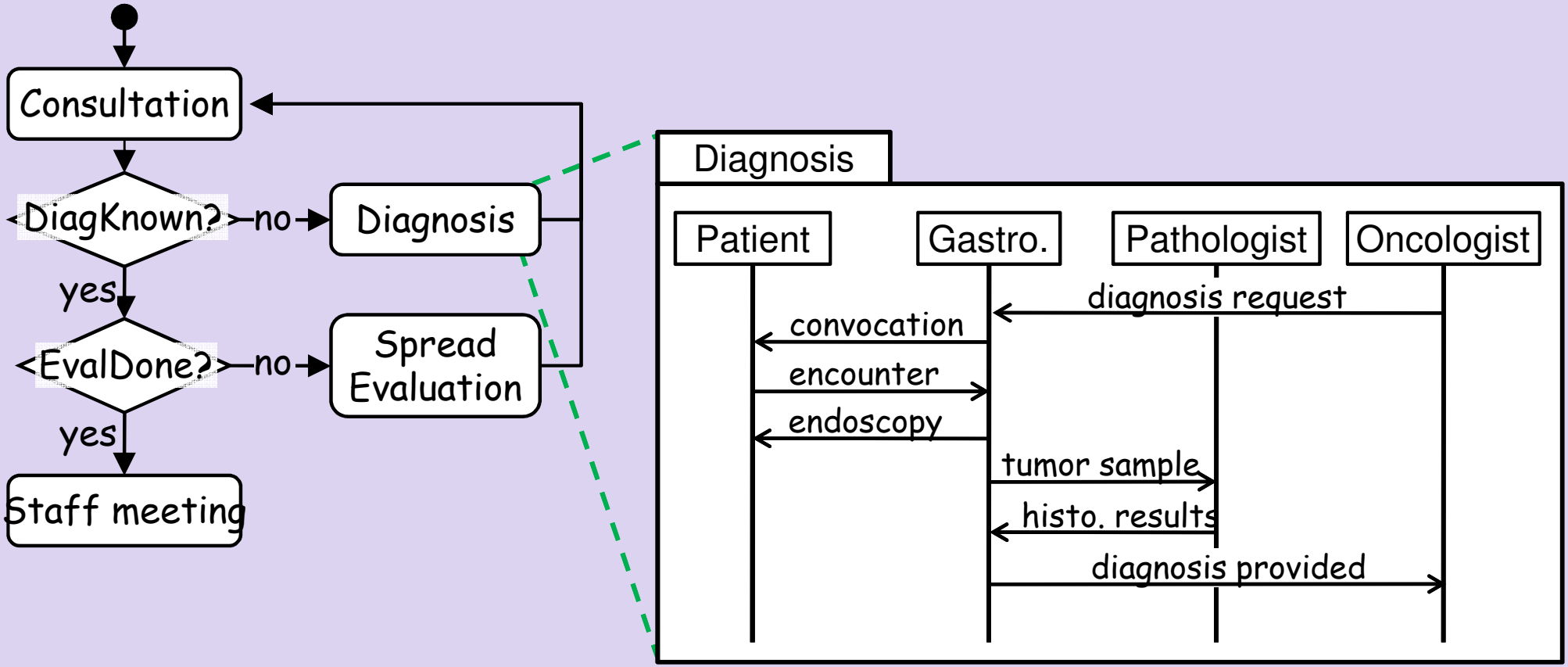
Requirements on critical process models

- Close to material provided by stakeholders
  - e.g. medical staff think naturally in terms of ...
    - therapy scenarios
    - sequencing of phases composed of tasks
    - decision trees
    - goals & properties on state variables about patient
- Formal semantics, techniques and toolset
  - to support model synthesis, verification and other analyses

Outline

- Guarded High-Level Message Sequence Charts as process modeling language
  - overview of modeling abstractions & semantics
- Abstract decorations for model analysis
  - motivation
  - abstract decoration algorithm
- Analyzing process models
  - verifying task preconditions
  - verifying timing requirements
  - detecting inadequate decisions

Guarded High-Level Message Sequence Charts



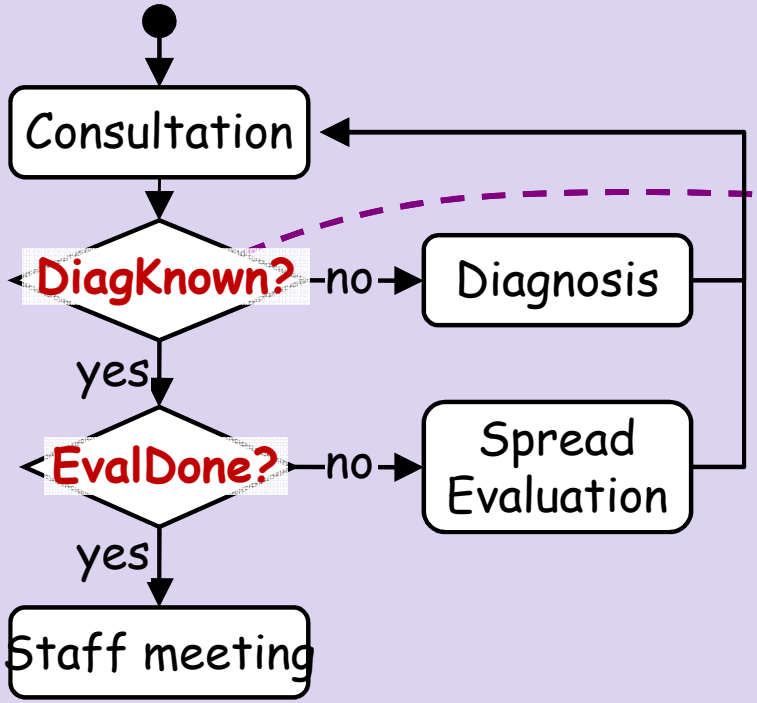
- Standard hMSCs + decision nodes
- Task nodes are specified by finer-grained guarded hMSCs or MSC scenarios
- Semantics in terms of Labeled Transition Systems (LTS)

Variables used in decision nodes
1 - Fluents

- Fluents encode task occurences as propositions

[Giannakopoulou & Magee 2003]

Fluent *Fl* = < $Init_{Fl}$, $Term_{Fl}$ >



Fluent *DiagKnown* =

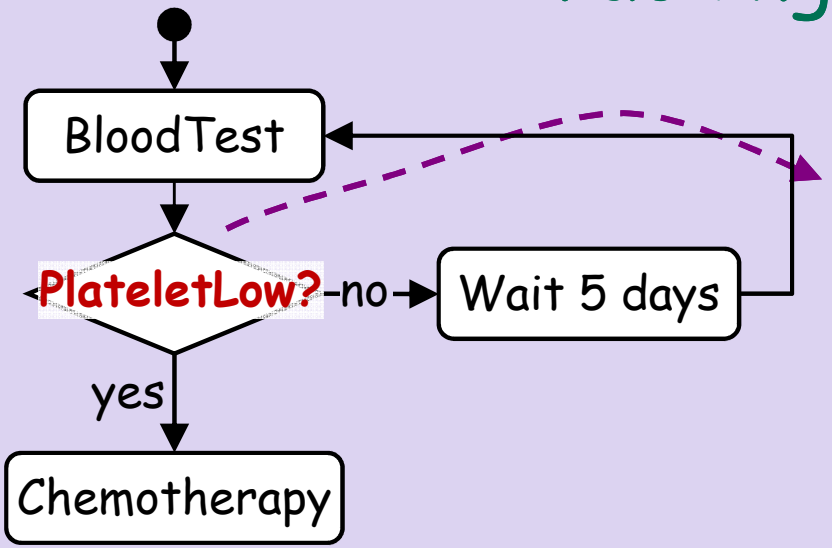
< {Diagnosis}, {FollowUp} >

"DiagKnown holds *after* Diagnosis and *until* FollowUp"

Variables used in decision nodes
2 - Tracking variables

- Variables tracking environment quantities
  - not directly observable by process agents

TrackingVar Tv = {$Update_{Tv}$}



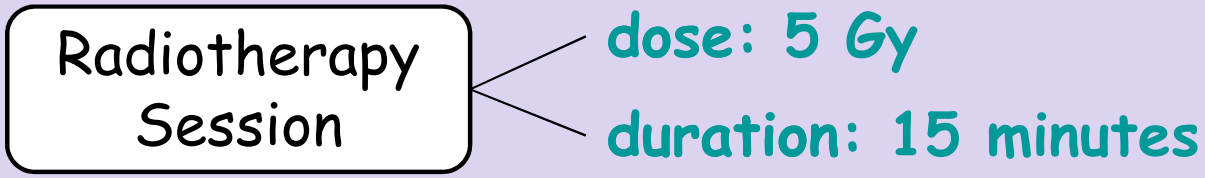
TrackingVar *PlateletLow* = {BloodTest}

"Platelet level is determined during BloodTest"

- Value not deterministically known (unlike fluents)
  - after BloodTest the platelel level may be low or not

Other abstractions

- Duration, doses, costs attached to tasks

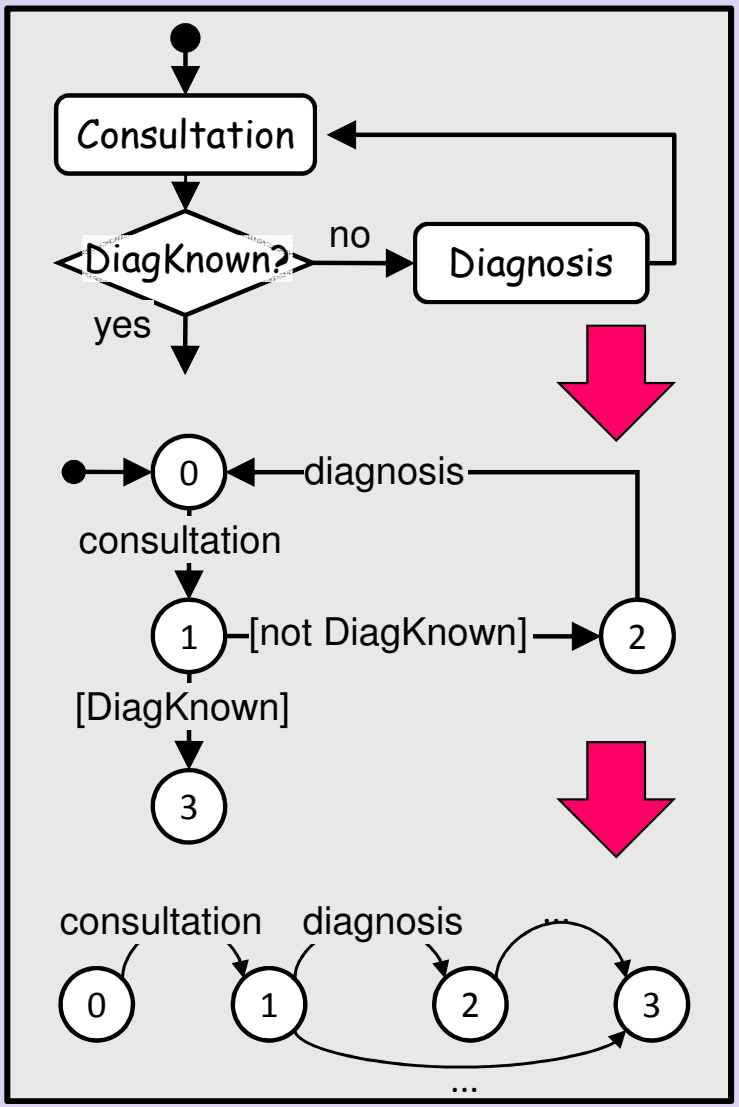


- Task preconditions

What kind of model analysis ?

- Checking task preconditions
  - "Radiotherapy may not take place if patient has already been irradiated in the past"
- Checking decision adequacy
  - "*Platelet level* in patient record should reflect the real patient's platelet level each time a related decision is taken"
- Checking non-functional requirements about timing , dosage, cost, etc
  - "Complete treatment may not exceed 40 days"
  - "Radiotherapy treatment must deliver exactly 45 Gy"

From process models to analyzable LTS



- Guarded hMSCs
  - process modeling language
- Guarded LTS =
  - Labeled Transition System with guards or events on transitions
- LTS
  - trace semantics
  - trace-based model checking

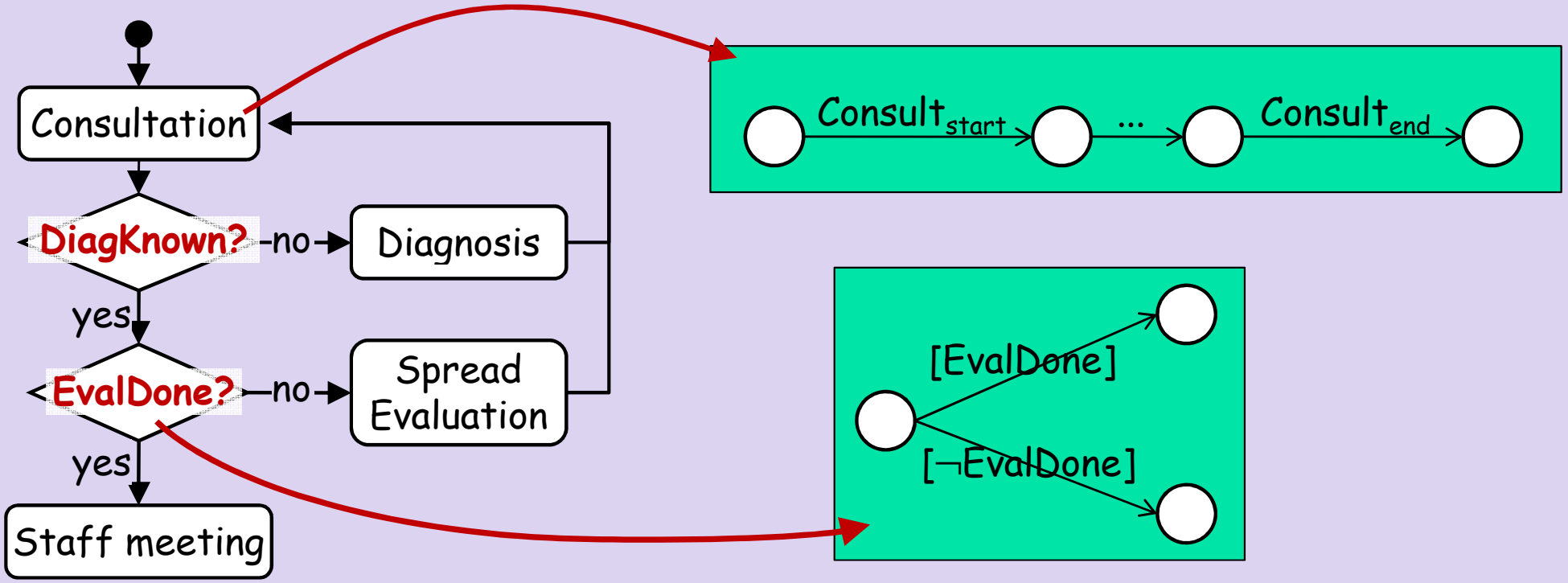
C. Damas, B. Lambeau, F. Roucoux and A. van Lamsweerde, "Analyzing Critical Process Models through Behavior Model Synthesis", *Proc. ICSE'2009: 31th International Conference on Software Engineering*, Vancouver, Canada

Abstract decorations for model analysis

- Computing the set of LTS traces accepted by a guarded hMSC ...
  - enables verification of temporal logic properties ...
  - ... but is time consuming ...
  - no support for reasoning about doses, timing, etc.

- Useful analyses can be performed on *guarded* LTS
  - avoid explicit trace enumeration
  - symbolically decorate states using well-chosen abstractions for specific analyses

From guarded hMSC to guarded LTS



- Task$_{start}$ and Task$_{end}$ events are introduced to support more accurate fluent definitions
  - refinements yield events between them
- "Bricks" are connected with τ transitions
  - mapping preserved between g-hMSC tasks and g-LTS states for analysis feedback

Decorating g-LTS models: a generic decoration algorithm

- Concrete decorations to be defined as instantiations over bounded lattices
  + initial decoration for initial state
- Abstract interpretation algorithm
  - generic propagation rule computes the effect of a transition on the decoration of a source state
  - generic decorations accumulated through supremum operator
- When fixpoint is reached ...
  - state decoration = accumulation of decorations contributed by all paths leading to the state

Process model analysis
1- Verifying task preconditions

- Decorations are Boolean expressions on the set of fluents and tracking variables
- Instantiated propagation rule handles guards & events

```
Propagate(deco, edge):
  if label(edge) is a guard
    return deco ∧ label(edge)
  else /* ... is an event */
    return deco|label(edge)
```

- Lattice supremum operator = disjunction on Bool lattice
- Check ...

for each source state of a $Task_{start}$ event:

decoration (source) |= $Task_{PRE}$?

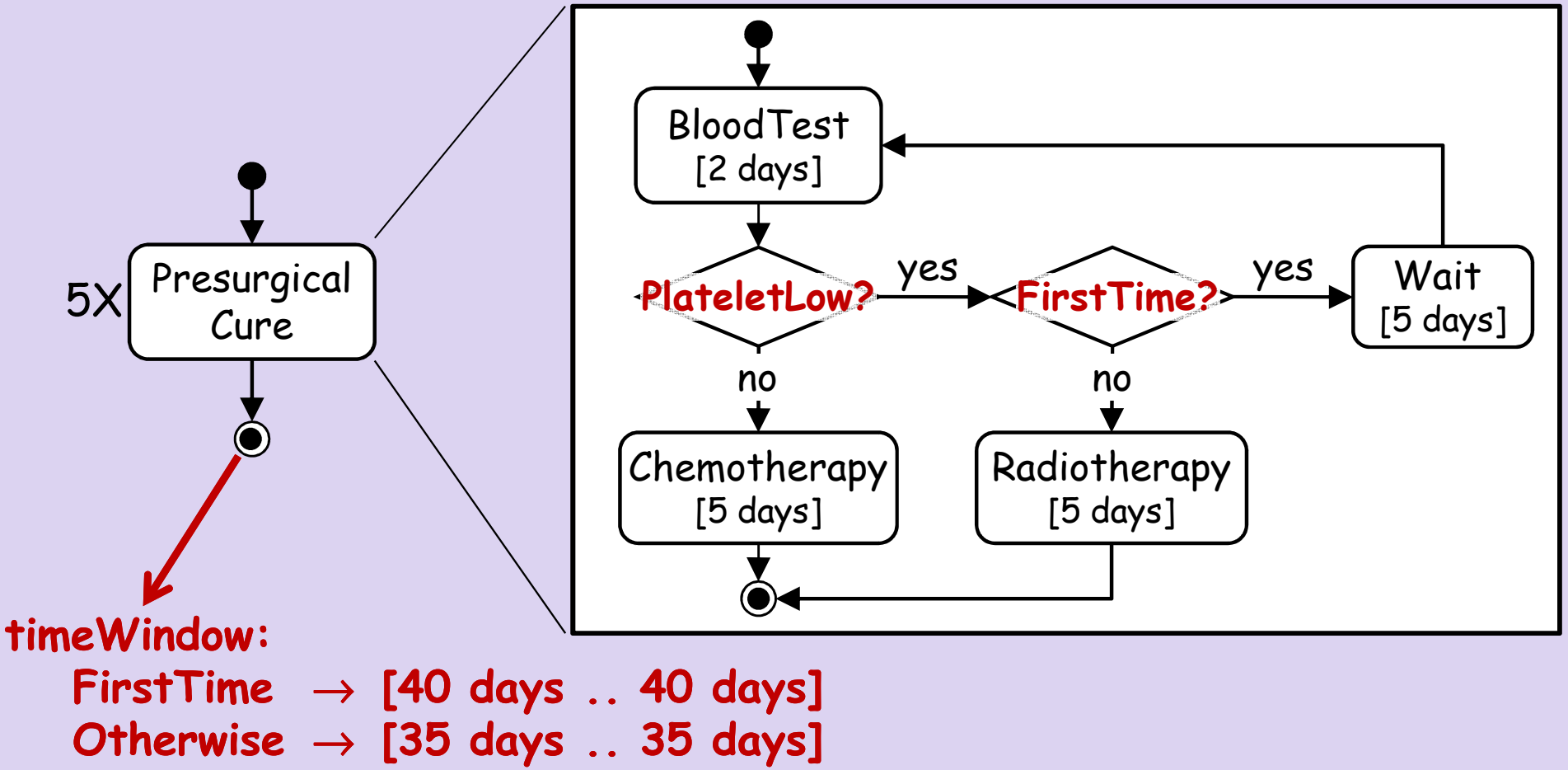
Process model analysis
2- Verifying temporal requirements

- Decorations are functions

$$\text{timeWindow}: 2^{\Phi} \rightarrow P\Re^{+}$$

  - Φ: set of all fluents & tracking variables
  - codomain: union of time intervals
  - map specific process instances to time points where the state can be visited
- Propagation rule
  - on guards: function restriction
  - otherwise interval is shifted to account for task duration
- Supremum
  - union of time intervals

Verifying temporal constraints: example



- Max 40 days -- ok!
- With similar technique: irradiation dose always exactly 45 Gy

3- Detecting inadequate decisions due to inaccurate information

- **Accuracy fluents** associated with tracking variables

  fluent *PlateletLowAccurate* =
  < {BloodTest}, {ChemoTherapy} > initially false

  " *The platelet level in the patient's record is accurate after BloodTest but should be considered inaccurate after ChemoTherapy* "

- Analysis: generate state invariants as g-LTS decorations
  - *PlateletLowAccurate* must always hold in source states of any guarded transition involving *PlateletLow*

4- Detecting inadequate decisions due to oudated information

- **Timed accuracy fluents** associated with tracking variables

  fluent *PlateletLowAccurate* =
  < {BloodTest}, {ChemoTherapy} > initially false
  duration 7 days

  " *The platelet level in the patient record is also considered outdated 7 days after a BloodTest* "

- Analysis: decorate g-LTS with state invariants while propagating timing information
  - blend of previous decoration types
  - same kind of check

Ongoing work

- In case of property violation, no counterexample generated so far
  - often required to understand the problem and correct the model
- Algorithm instantiations for other kind of analyses
  - e.g. resource usage
- Domain properties to be introduced in the model for simplifying derived information such as preconditions
- Goals underlying tasks should be made explicit