Conformance verification of careflow process executions: a case study on cancer screening

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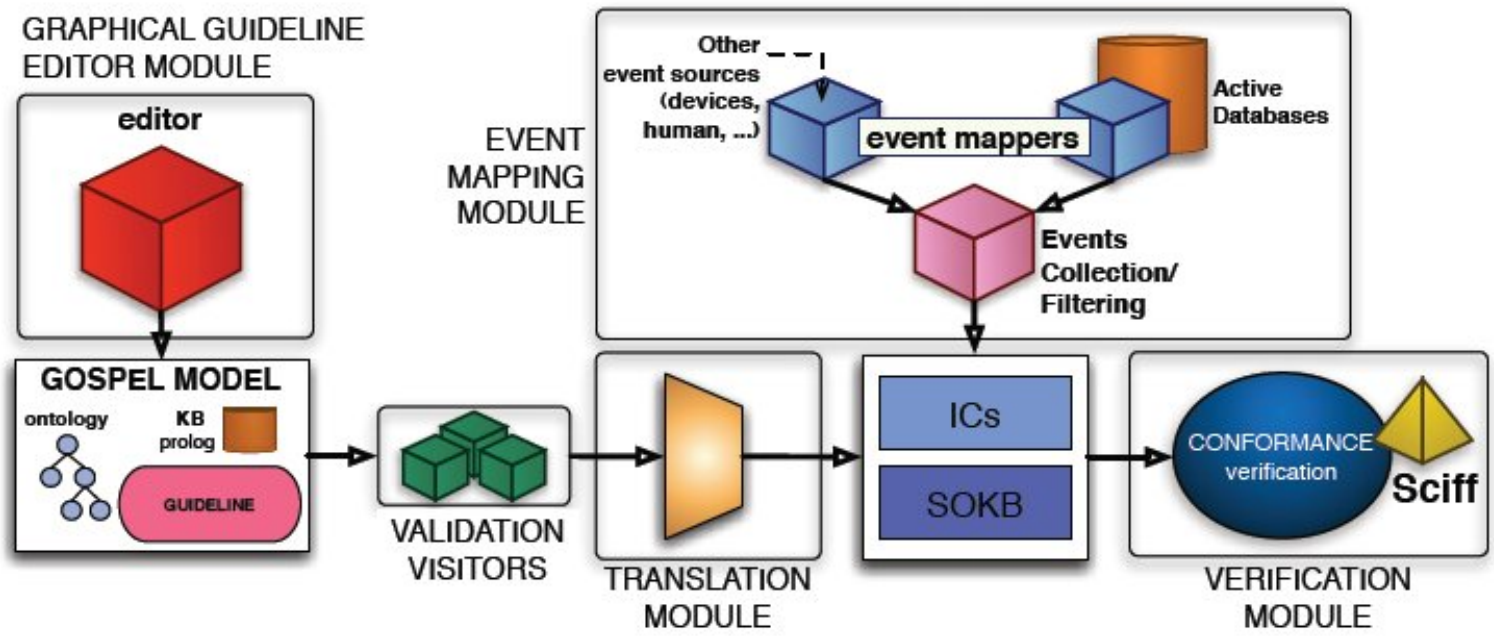
Medical guidelines and protocols

- Medical guidelines and protocols are used to improve the quality of medical care

- A medical protocol is the implementation of a guideline in a specific environment
  - Modeled as a careflow: medical actors receive objects, perform activities, operate under rules, and transmit objects to other actors
  - Components of a careflow:
    - Actors: patients, physicians, instruments, software agents
    - Objects: data, documents, images, physical samples
    - Activities: processes, actions, computations
    - Rules: constraints, conditions, limits, boundaries

Careflow conformance verification

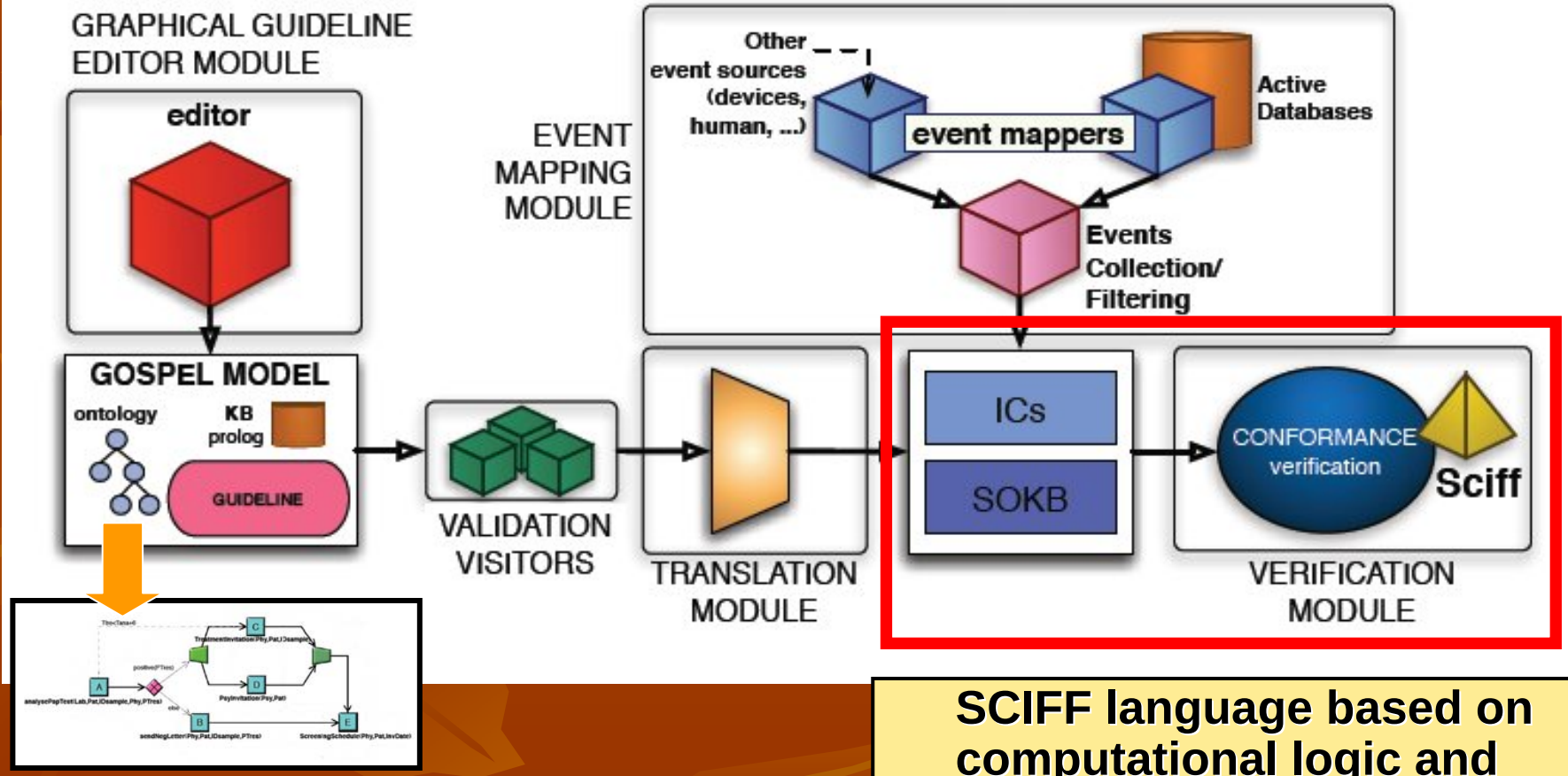
- Careflow conformance verification to identify:
  - Wrong participant behaviors
  - Parts of the protocol not well defined



Graphical guideline editor: GOSpeL

- Simple graphical language for specifying the careflow process
- The GOSpeL representation of a careflow consists of:
  - a flow chart, which models the careflow evolution
  - a domain ontology for specifying actors, activities, and objects of the careflow
- Ontology management by using the PROTÉGÉ-2000 API

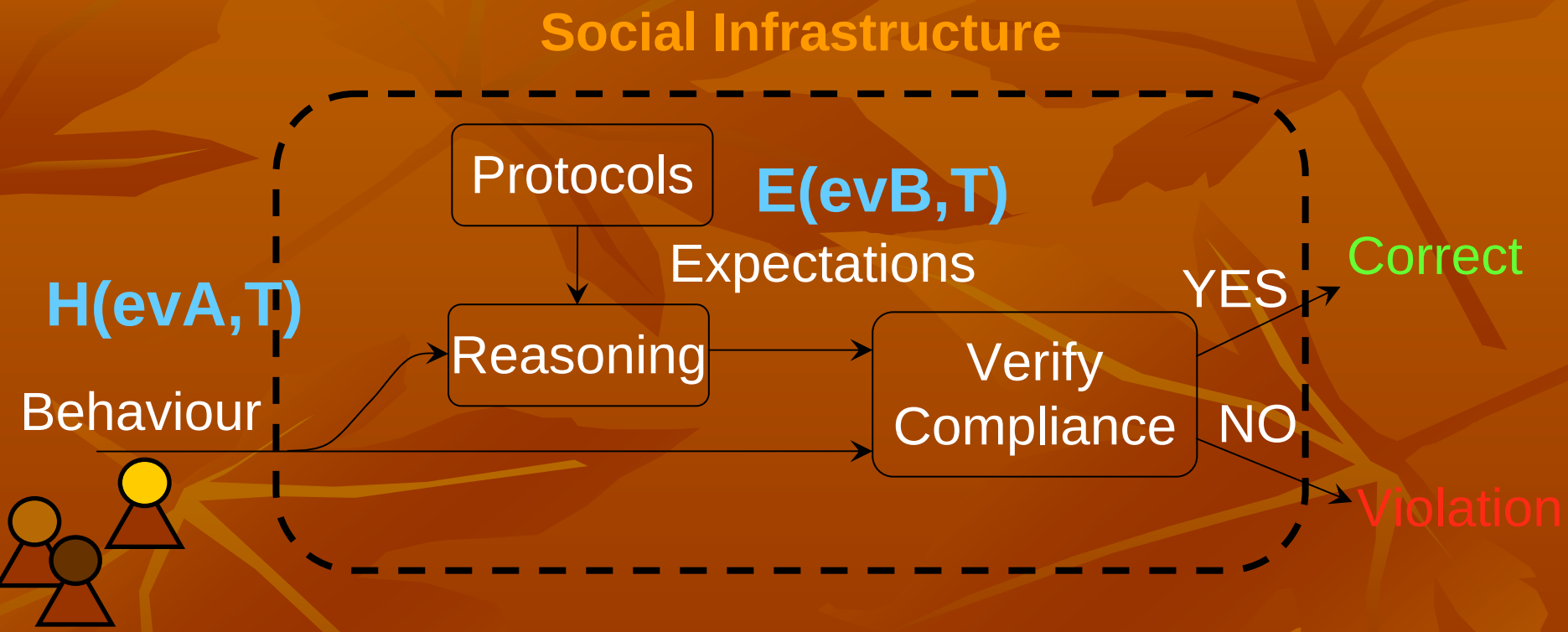
Careflow conformance verification



SCIFF language based on computational logic and abductive proof procedure

(SOCS European project)

SCIFF framework



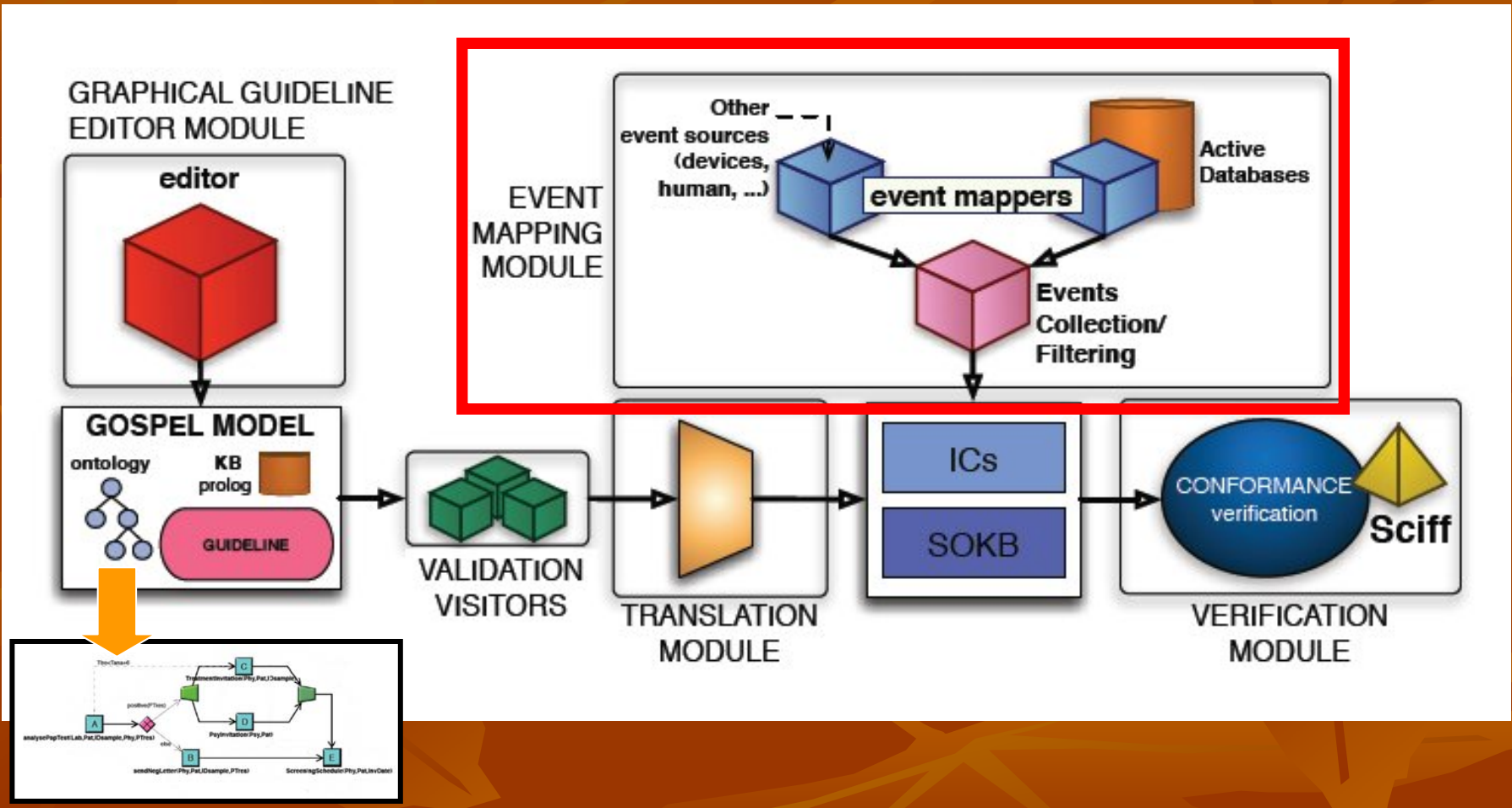
Integrity Constraints (IC): body → head

H(ask(A,B,Something), T1)) -->
E(ansyes(B, A, Something), T2) ∧ T2 ≥T1
E(ansno(B, A, Something), T2) ∧ T2 ≥T1

Verification module

- The SCIFF Proof Procedure:
  - processes the events: for each event it looks for a possible “unification” with the body of one (or more) SIC
  - for each IC whose “body” is verified by the events, the expectations defined in the head are generated.
  - detects two types of violations:
    - **H** with **EN:** an actor performs activities explicitly not expected by the careflow
    - **E** without **H**: an actor does not act as expected by the careflow
    - **H** without **E**: an actor performs activities not expected by the careflow

Careflow conformance verification

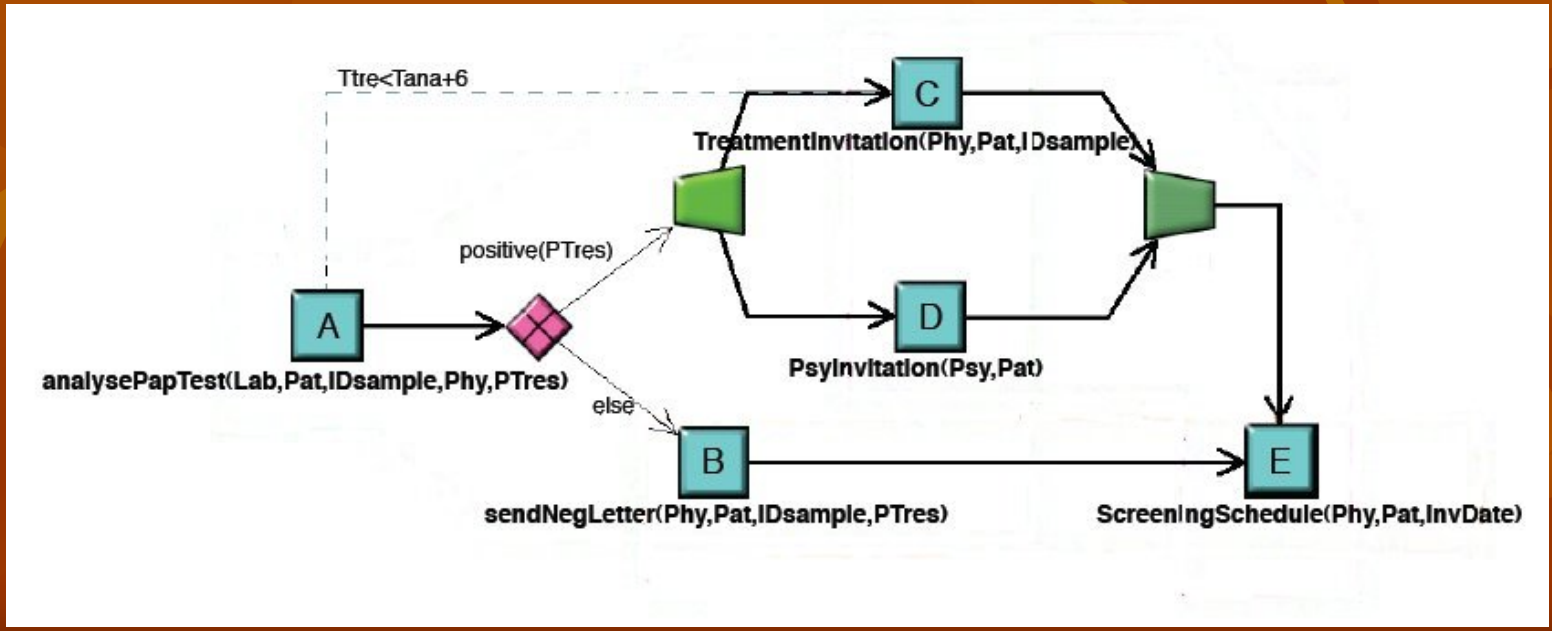


SPRING project

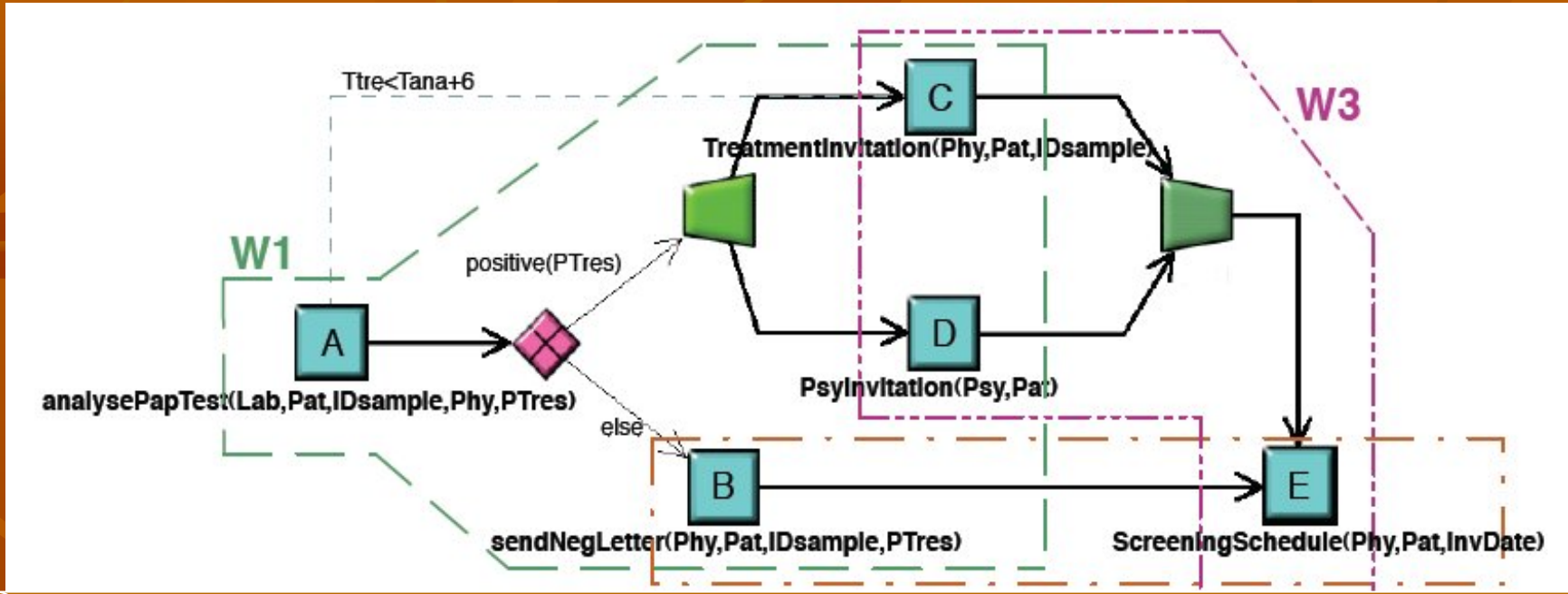
- Joint project of the Emilia Romagna region of Italy: ENDIF – Univ. Ferrara; DEIS – Univ. Bologna; NOEMALIFE Bologna; Screening Center Bologna
- Project GOAL: to support definition and verification of cancer screening protocols
- Cancer screening to early detect and treat cancer (cervical, breast and colorectal cancers)
- Case study on cervical cancer

Careflow example

- The Lab (actor) analyzes a pap-test IDsample (object) executed on a patient Pat (actor) and sends the results PTres (object) to a physician Phy (actor). Phy evaluates IDsample as positive or negative. If positive, Phy invites (within 6 days) Pat for a treatment and a psychologist Psy (actor) invites Pat for a consultation. If negative, Phy sends a negative pap-test letter to Pat. Finally, Phy schedules the next pap-test for Pat.



Translation of W1



Translation of W1

H(analysePapTest(Lab,Pat,IDsample,Phy,PTres),Tana)
→
positive(PTres)
∧ **E**(treatmentInvitation(Phy,Pat,IDsample),Ttre)
∧ **E**(psyInvitation(Psy,Pat),Tpsy) ∧ Ttre > Tana ∧ Ttre < Tana + 6 ∧ Tpsy > Tana

∨
not(positive(PTres))∧ **E**(sendNegLetter(Phy, Pat, IDsample, PTres), Tsen)∧ Tsen > Tana

Example of conformant history

Happened Events

```
H(analysePapTest(lab1, pat1, 123, phy1, [results]), 5)
H(psyInvitation(psy1, pat1), 7)
H(treatmentInvitation(phy1, pat1, 123), 10)
H(screeningSchedule(phy1, pat1, 15apr2007), 30)
```

Expectations

Start

```
E(analysePapTest(Lab, Pat, IDSample, Phy,PTRes), Ta)
```

Generated by IC1 supposing positive([results]) = true

```
E(psyInvitation(psy1, pat1), Tpsy)                Tpsy > 5
E(treatmentInvitation(phy1, pat1, 123), Ttre) 5 < Ttre < 11
```

Generated by IC3

```
E(screeningSchedule(phy1, pat1, Date), Tsche) Tsche > 10
```

Example of violation (1/2)

Happened Events

```
H(analysePapTest(lab1, pat1, 123, phy1, [results]), 5)
H(psyInvitation(psy1, pat1), 7)
H(treatmentInvitation(phy1, pat1, 123), 15)
```

Violation of the time constraint

Expectations

Start

```
E(analysePapTest(Lab, Pat, IDSample, Phy,PTRes), Ta)
```

Generated by IC1 supposing positive([results]) = true

```
E(psyInvitation(psy1, pat1), Tpsy)      Tpsy > 5
E(treatmentInvitation(phy1, pat1, 123), Ttre)  5 < Ttre < 11
```

Example of violation (2/2)

Happened Events

```
H(analysePapTest(lab1, pat1, 123, phy1, [results]), 5)

H(sendNegLetter(Phy1, Pat1, 123, [res1, …, resn]), 10)
```

The protocol evaluates the pap-test as positive but the physician as negative and behaves as negative

The physician performs an activity not expected by the careflow

These Expectations are not fullfilled

Expectations

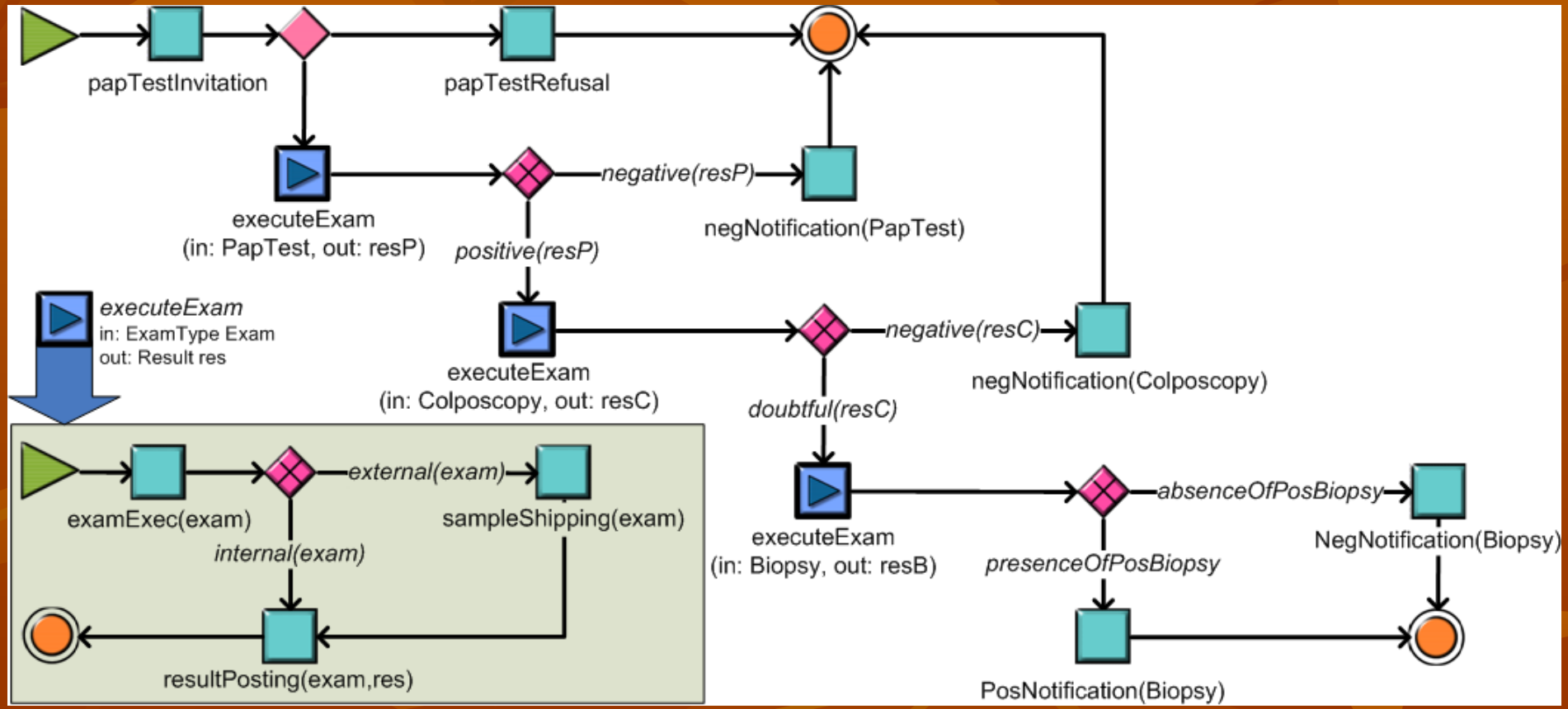
Start

```
E(analysePapTest(Lab, Pat, IDSample, Phy,PTRes), Ta)
```

Generated by IC1 supposing positive([results]) = true

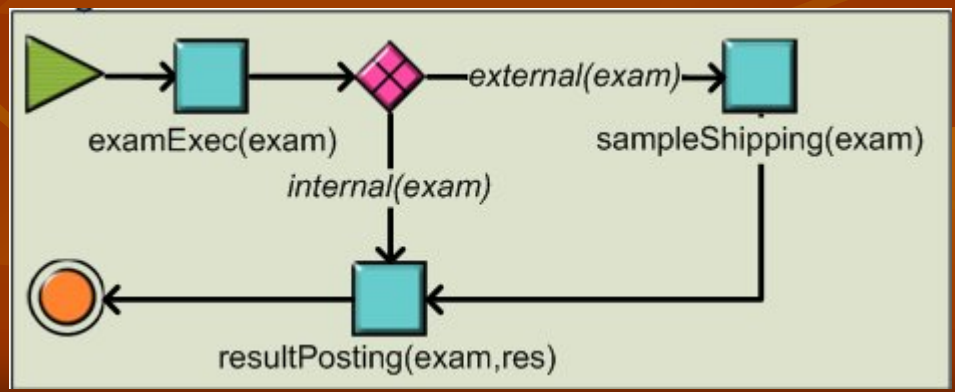
```
E(psyInvitation(psy1, pat1), Tpsy)     Tpsy > 5
E(treatmentInvitation(phy1, pat1, 123), Ttre) 5 < Ttre < 11
```

Screening careflow model in SPRING



Traslation of the careflow model

- The careflow model is translated in 14 ICs
- executeExam translation:
  - H(eseguiEsame(TipoEsame,IdEsame),Tesa) /\ analisi_esterna(TipoEsame)
    → E(invioCampione(TipoEsame,IdEsame),Tinv) /\ Tinv > Tesa.
  - H(eseguiEsame(TipoEsame,IdEsame),Tesa) /\ analisi_interna(TipoEsame)
    → E(invioRisultato(TipoEsame,IdReferto,Esito), Tris) /\ Tris > Tesa.
  - H(invioCampione(TipoEsame,IdEsame),Tinv)
    → E(invioRisultato(TipoEsame,IdReferto,Esito),Tris) /\ Tris > Tinv.



Screening event log

- Database of the screening center translated in event log
- Some incorrect behaviours have been randomly introduced in the event log
- The resulting event log consists of 1950 careflow process executions:
  - Shortest careflow process execution consists of one event (the invitation to take part to the screening followed by no response)
  - Longest careflow process execution consists of 18 events (representing the whole careflow plus the repetition of some laboratory exams due to an undecidable analysis result).
  - The average number of events is 4

Conformance verification results

- Conformance verification execution time:
  - 30 min Total and 1sec Average
- Conformance result:
  - 877 Conformant executions over 1950
- Analysis of non conformant careflow process executions:
  - Executions classified as conformant were confirmed
  - Some particular executions were erroneously classified as non conformant:
    - We introduces some special abducibles in the ICs:
      - To classify these executions as conformant
      - To warn about special executions
- Second verification round: 64 executions are still not conformant (“wrong behaviour” introduced in the database and some insights)

Conclusions

- Use computational logic to verify conformance of participant behaviors within a careflow
- Our approach proposes:
  - Formal language to model the careflow
  - Abductive proof procedure to verify the conformance
- Case study on cervical cancer screening

Future works

- Change GOSpeL with another graphical guideline modeling notation:
  - GLARE: joint work with Terenziani/Bottrighi
  - ASBRU
  - Etc..
- Use gSCIFF:
  - Properties verification

Thank you!

References

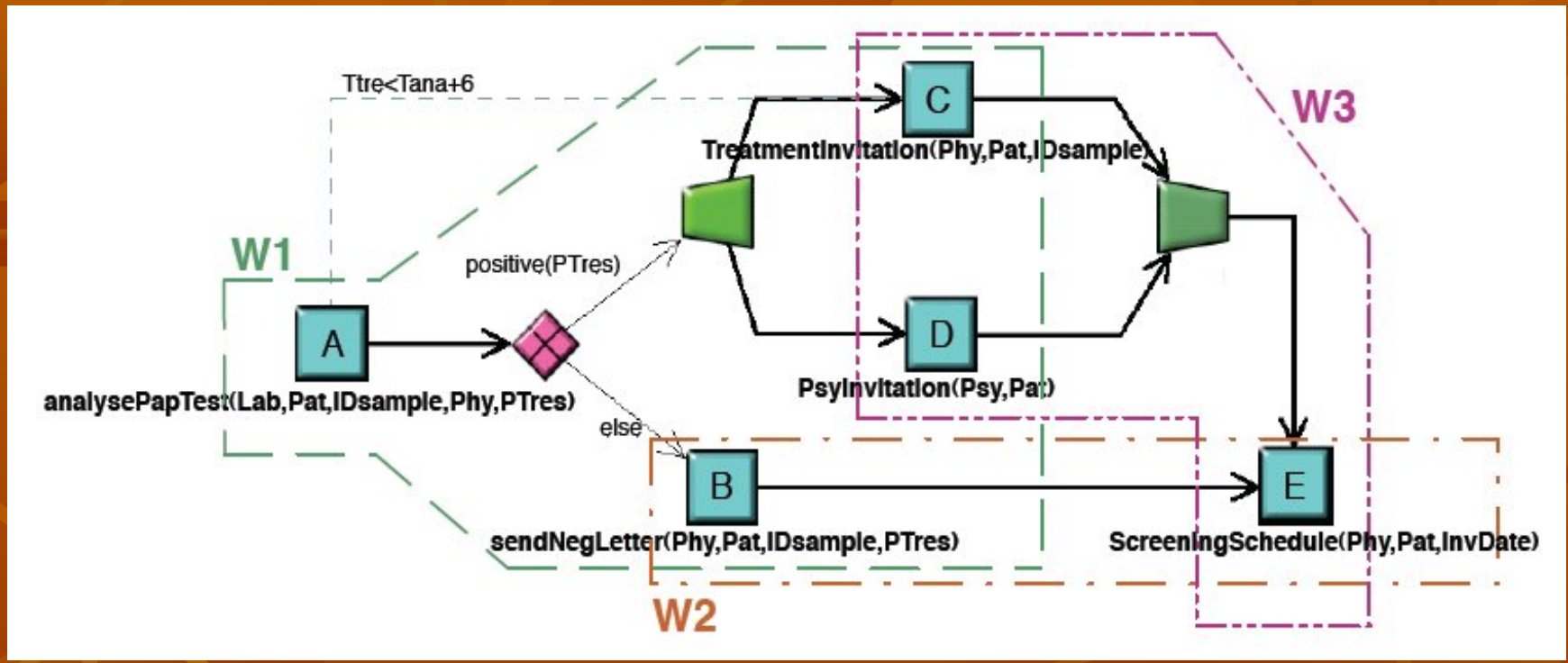
Publications

- Ciampolini A, Mello P, Montali M, Storari S, *Using social integrity constraints for on-the-fly compliance verification of medical protocol.* In: A. Tsymbal, P. Cunningham, eds: Proceedings of eighteenth IEEE Symphosium on Computer Based Medical Systems (CBMS) 2005. IEEE Press, 2005: 503-505
- Chesani F, Ciampolini A, Mello P, Montali M, Storari S. *Testing guidelines conformance by translating a graphical language to computational logic.* The ECAI 2006 international workshop on Artificial Intelligence in Healthcare: evidence-based guidelines and protocols. Printed by the organizers and available online at http://www.cs.vu.nl/~annette/FinalVersions/Chesani.pdf . 2006
- M. Alberti, F. Chesani, M. Gavanelli, E. Lamma, P. Mello, M. Montali, S. Storari. *Abduction for Specifying and Verifying Web Service Choreographies.* The ECAI 2006 4th International Workshop on Artificial Intelligence for Service Composition 2006. Printed by the organizers and available online at http://ecai2006.itc.it/AISC06/W29.pdf . 2006:15-20.

Web references:

- **The SCIFF Abductive Proof Procedure:**
  http://www-lia.deis.unibo.it/research/sciff/

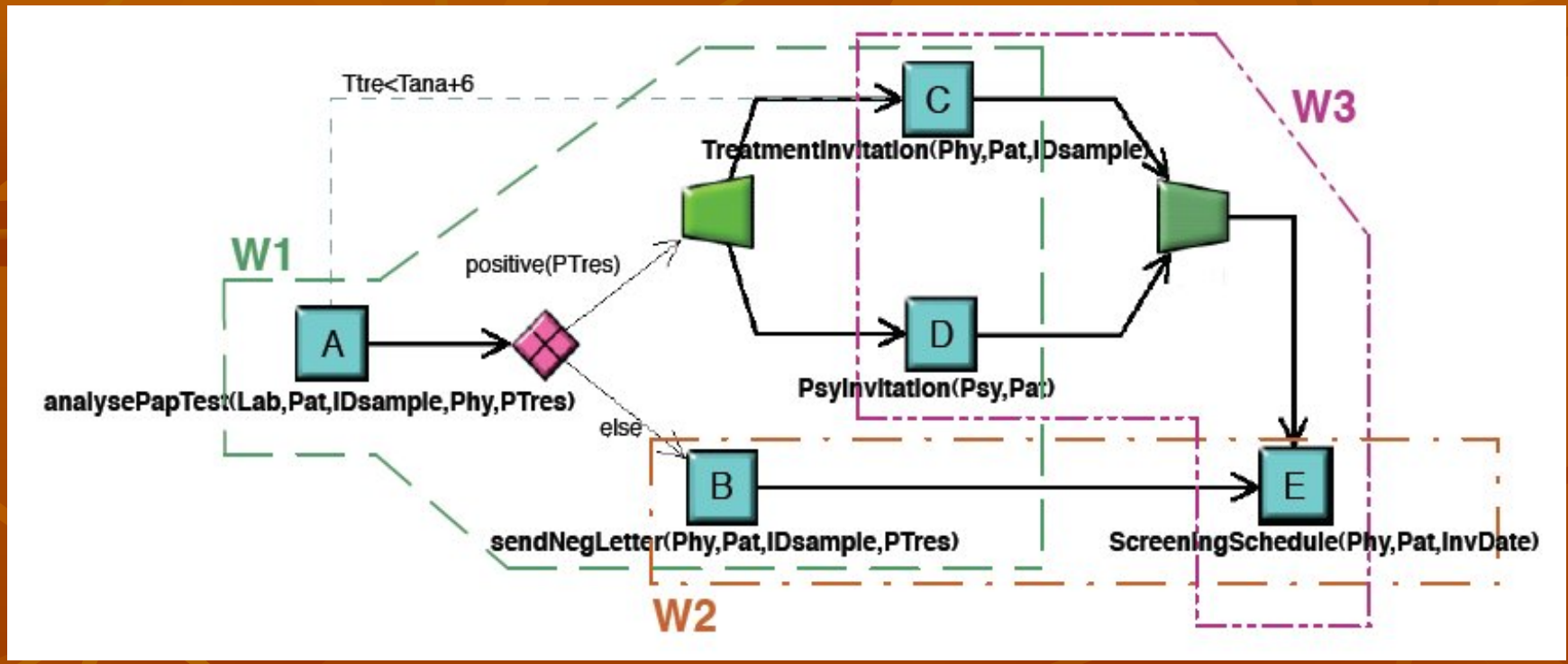
Translation of W2



Translation of W2

H(sendNegLetter(Phy, Pat, IDsample, PTres), Tsen)
→
E(screeningSchedule(Phy,Pat,InvDate),Tscr) ∧ Tscr > Tsen

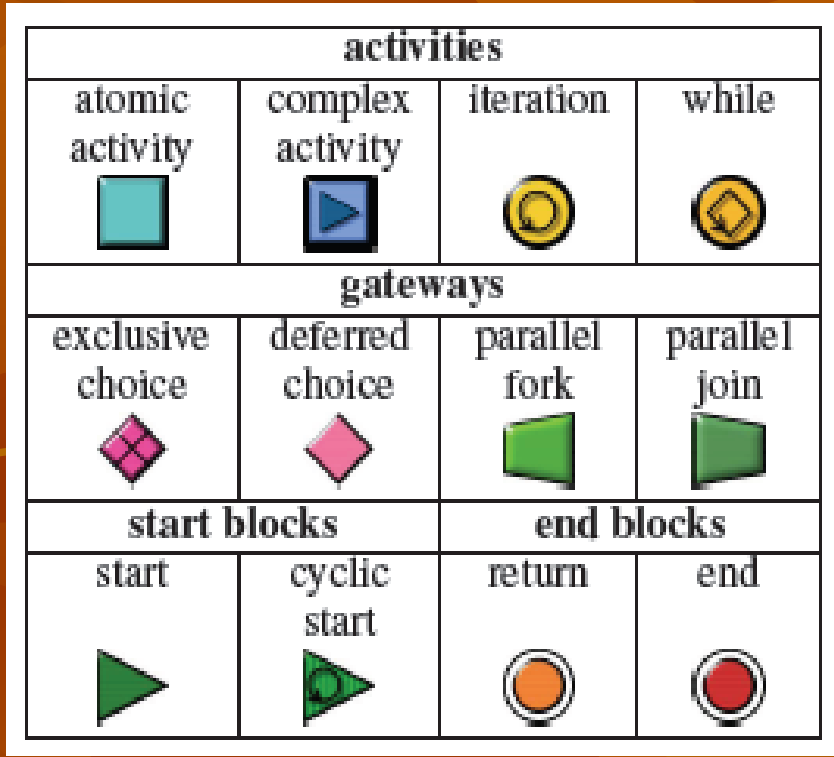
Translation of W3



Translation of W3

$\mathbf{H}(\text{treatmentInvitation}(Phy,Pat,IDsample),Ttre) \wedge \mathbf{H}(\text{psyInvitation}(Psy,Pat),Tpsy)$
$\rightarrow$
$\mathbf{E}(\text{screeningSchedule}(Phy,Pat,InvDate),Tscr) \wedge Tscr > Ttre \wedge Tscr > Tpsy$

GOSpeL graphical elements



Idea behind the translation (1/2)

- Some GOSpeL blocks can be mapped into events (event-blocks):
  - Activity blocks represent events specified by:
    - name of the associated ontological activity
    - variables representing formal participants
    - Example: hold(Phy,Pat)
  - START / END blocks represent special events
- Each translation starts from an event-block A:
  - This event A is supposed to happen
  - The relations after A in the model describe what it is expected to happen after A

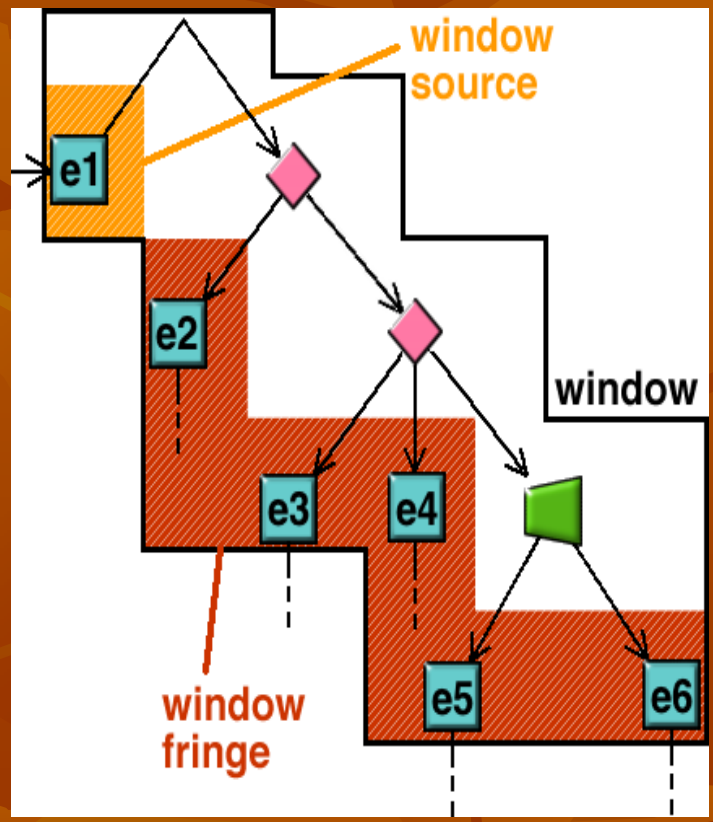
Idea behind the translation (2/2)

- The meaning of a translation in a SIC:
  - The body represents that an event is happened
  - The head represents what the model prescribe to happen after this event
- The model is translated in a set of SIC

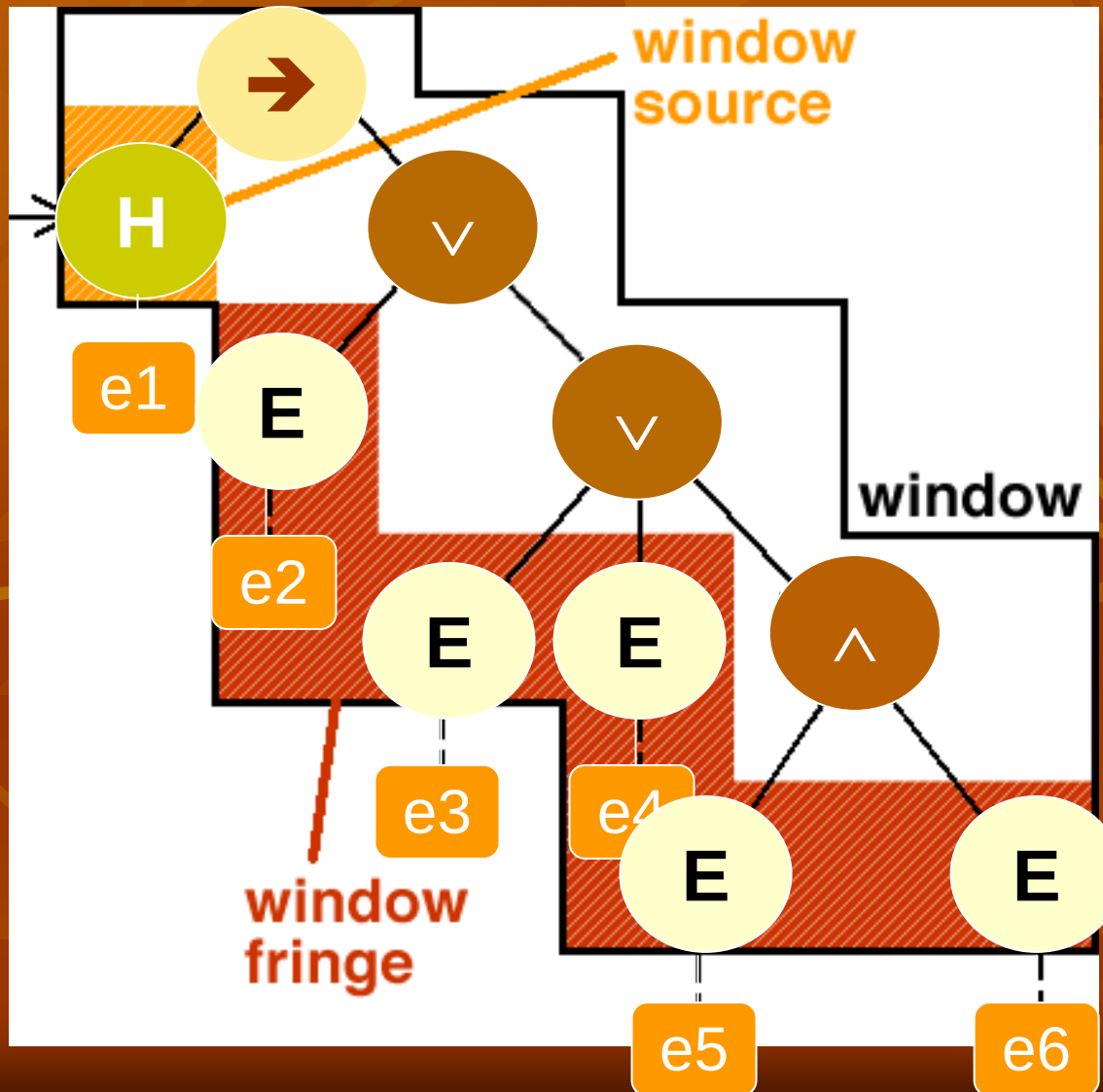
- Two issues:
  - Isolate a part of the model that can be mapped in a SIC
  - Build a recursive translation algorithm

Definition of Minimal windows

- A group of contiguous blocks
- Properties:
  - Window source and fringe must contain only event-blocks
  - Inside the window there must be only split and/or merge blocks (minimal)
  - All the outgoing (ingoing) relations exiting from (going to) a split block (merge block) must be considered
- Each minimal window is translated into a SIC



Translation of GOSpeL



Translation of a minimal window

- Events in the window source became **H**
- Events in the window fringe became **E**
- Gateways inside the window contribute to the SIC structure:
  - Deferred choice: a disjunction of events is inserted in the head
  - Exclusive choice: a disjunction of events is inserted in the head and a logic condition is associated to each alternative flow
  - Parallel split: a conjunction of events is inserted in the head
  - Parallel join: a conjunction of events is inserted in the body

GPROVE framework architecture