Workflow Management for Health Care Processes Meets Formal Verification

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*With valuable input & discussions from Wang, Mashiyat, Leyla, Crawford, Graham, Jewers and numerous clinicians and managers from GASHA

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Motivational Problem: Health Services Delivery

- Health care is approaching a crisis (2009-$192B)
- IT is 20-30 out of date - largely for accounting purposes
- People demanding more and more services
- Work to develop EHRs --- little other IT to support it
- Need for Patient-centred and Collaborative Care
- Guidelines/Standards are common --- how to measure and track care and ensure compliance?
- Health care is variable & distributed process – subject to patient needs, resources of Health Authority
- Safety critical process – money and lives are at stake

Over-riding Goal

- My Slogan: *Put science into software*
  - Quality assurance
  - Intelligence

- In Healthcare – the product is the "outcome"; studies show that having and following "good" (evidence-based) process leads to improved outcomes.

- So we focus on the process

PcCfMS

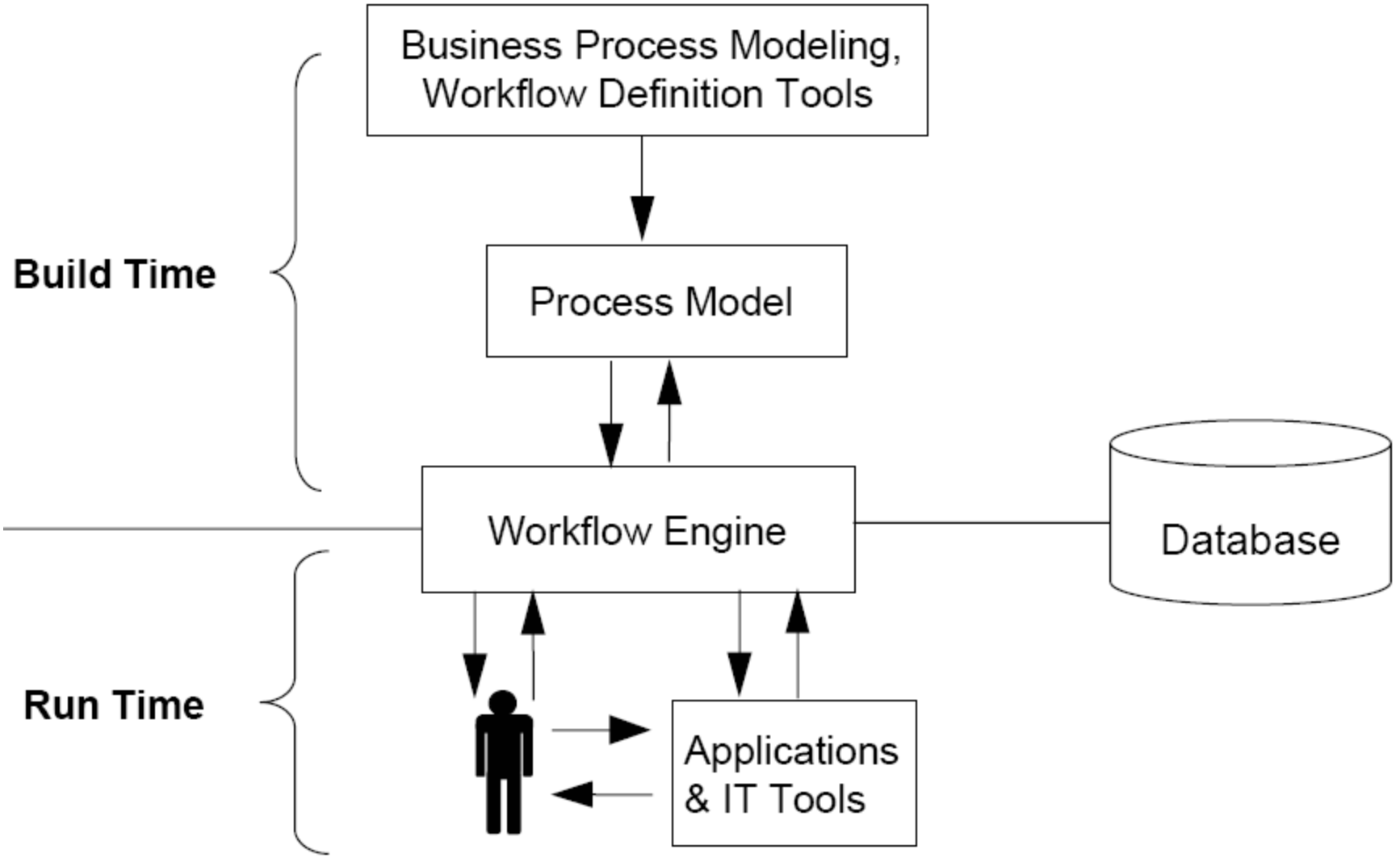
- Collaborative R&D project involving
  - Computer scientists & nurses from academia
  - Clinicians & managers from the local health authority (GASHA)
  - Industry partner: Palomino Innovation Systems Inc.
- Goal: a platform for a web-based workflow management system (PcCfMS) for community-based programs
- Two programs: seniors' wellness and palliative care (easily adaptable to chronic illnesses)
- Develop & pilot communication, documentation and process management system to promote collaborative patient-centred care.

Workflow management system (WfMS)

- Workflow management system: a computer system to promote the management of work and information in dynamic and distributed organizations

  - Provides consistent output
  - Facilitates visualization of actual work
  - Systematic organization of resources
  - Reduces waste and duplication of work
  - Facilitates documentation
  - Improves efficiency

Components of WfMS



What is Missing??

- Advanced error handling/compensation for changes
- Quality assurance – guarantee that system is designed to satisfy properties every time
- Monitoring
- Generally lacks flexibility/intelligence

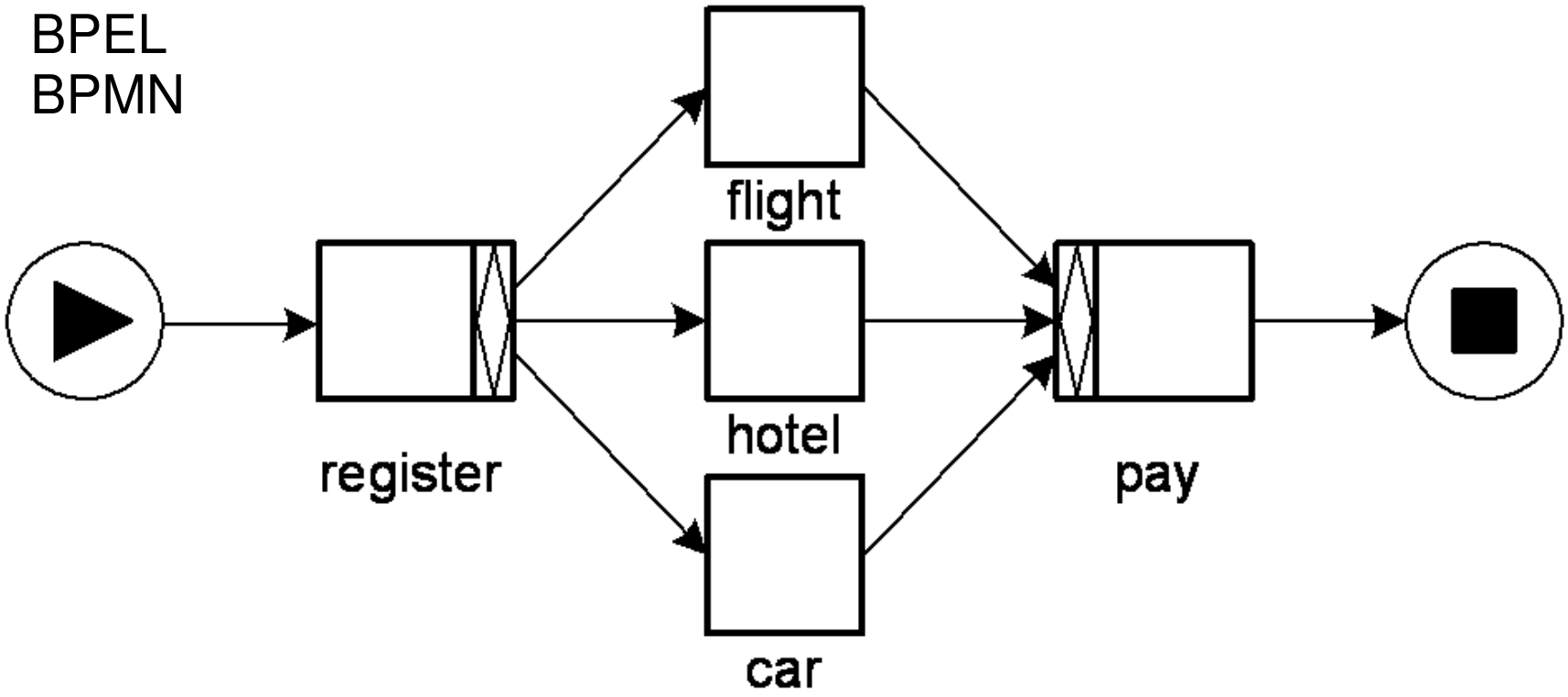
Prototype - NOVA WorkFlow

- compeNsable Ontology-driven Verifiable Adaptive Workflow Management System
- (made in Nova Scotia!!)

- Graphical Editor for Compensable Transactions
- Automated Translator to a Verification Engine
- Workflow as a Service to support various client applications
- (working on integration with ontology to guide workflow; first component almost ready involves access control)

Workflow Languages

- Petri-nets
- Workflow nets
- YAWL
- BPEL
- BPMN



Traditional transaction system

Guarantees that database transactions are processed reliably by **ACID** properties

ACID is an acronym for

- **Atomicity**
- **Consistency**
- **Isolation**
- **Durability**

Traditional transaction system (cont)

Problem of this transactional system:

Cannot handle long running transactions

What is a long running transaction?

- It has lengthy computation
- It requires long time to complete
- It stops for input from users
- It has sub transactions

Why ACID transactions are not good for long running transactions:

- It requires database and resource locking
- For long running transactions it increases the chance for deadlock
- For web service transactions services are generally independent and autonomous- sometimes they belong to different companies

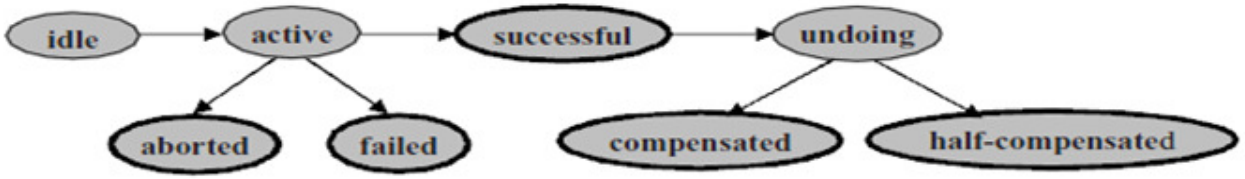
Compensable transaction

A compensable transaction is a new type of transaction whose effect can be semantically undone even after it has committed.

It consists of two parts:

1. Forward flow
2. Compensation flow

The behavior structure is described as a state transition diagram:



$$\Sigma = \{idl, act, suc, abt, fal, und, cmp, hap\}$$

$$\Delta = \{suc, abt, fal, cmp, hap\}$$

t-Calculus

- *t*-calculus is the transactional composition language of compensable transactions (Jefing He etc.)
- The syntax of *t*-calculus is made up of several operators, each operator can be semantically defined by a series of behavioral dependencies.

Sequential Composition	$S \; ; \; T$	Parallel Composition	$S \parallel T$
Internal Choice	$S \sqcap T$	Speculative Choice	$S \otimes T$
Alternative Forwarding	$S \rightsquigarrow T$	Backward Handling	$S \trianglerighteq T$
Forward Handling	$S \triangleright T$	Programmable Compensation	$S \divideontimes T$

Compensable Task

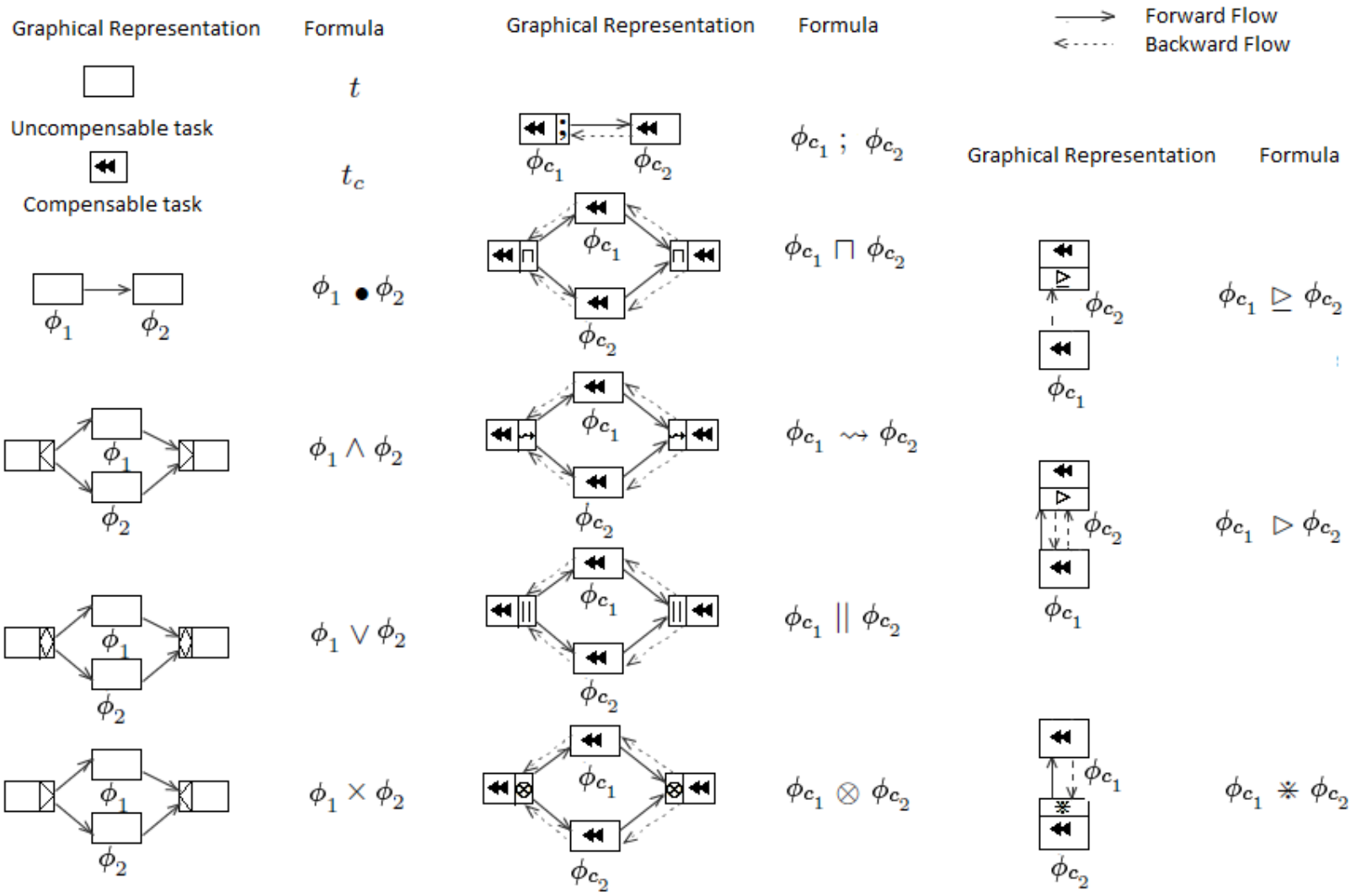
Definition *A compensable task (ϕ_c) is recursively defined by the following well-formed formula:*

$$\phi_c = t_c \mid (\phi_c \odot \phi_c)$$

where t_c is an atomic compensable task, and $\odot \in \{;, \|, \sqcap, \otimes, \rightsquigarrow, \trianglerighteq, \rhd, \divideontimes\}$ is a t-calculus operator defined as follows:

- ϕ_{c_1} ; ϕ_{c_2}: *ϕ_{c_2} will be activated after the successful completion of ϕ_{c_1},*
- $\phi_{c_1} \| \phi_{c_2}$: *ϕ_{c_1} and ϕ_{c_2} will be executed in parallel. If either of them (ϕ_{c_1} or ϕ_{c_2}) is aborted, the other one will also be aborted,*
- $\phi_{c_1} \sqcap \phi_{c_2}$: *either ϕ_{c_1} or ϕ_{c_2} will be activated depending on some internal choice,*
- $\phi_{c_1} \otimes \phi_{c_2}$: *$\phi_{c_1}$ and ϕ_{c_2} will be executed in parallel. The first task that reaches the goal will be accepted and the other one will be aborted,*
- $\phi_{c_1} \rightsquigarrow \phi_{c_2}$: *$\phi_{c_1}$ will be activated first to acieve the goal, if ϕ_{c_1} is aborted, ϕ_{c_2} will be executed to achieve the goal,*
- $\phi_{c_1} \trianglerighteq \phi_{c_2}$: *if ϕ_{c_1} fails during execution, ϕ_{c_2} will be activated to remove the partial effects remaining in the system. ϕ_{c_2} terminates the flow after successfully removing the partial effects,*
- $\phi_{c_1} \rhd \phi_{c_2}$: *if ϕ_{c_1} fails, ϕ_{c_2} will be activated to remove the partial effects. ϕ_{c_2} resumes the forward flow to achieve the goal,*
- $\phi_{c_1} \divideontimes \phi_{c_2}$: *if ϕ_{c_1} needs to undo its effect, the compensation flow will be redirected to ϕ_{c_2} to remove the effects.*

Compensable Workflow Modeling Language (CWML)



DiVinE (Distributed Model Checker)

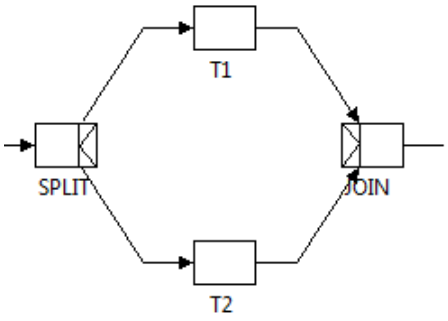
- LTL model checker
- Can effectively handle the well known “state explosion problem”
- Open source

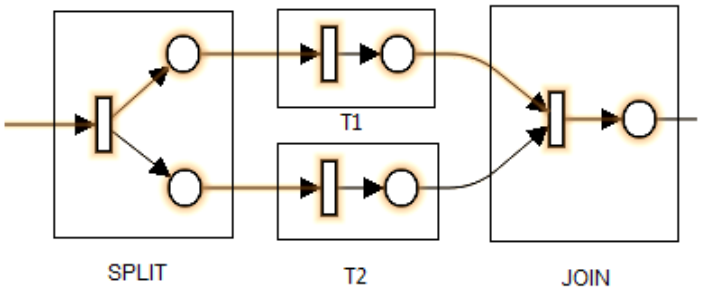
But:

- Modeling in DVE (or modeling language of any model checker) is tedious and error prone

Translation of And Split-Join block

Petri net diagram of And Split-Join block and its transcription to DVE



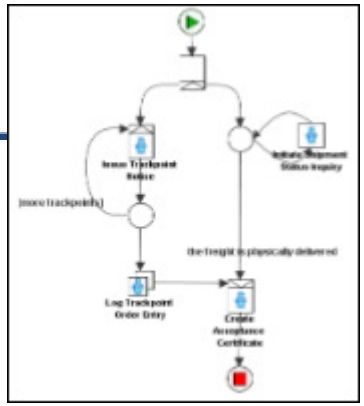



```
process Proc_T1{
        tate tr;
        init  tr;
        trans
        tr -> tr{ guard var_P1 >= 1;

          effect   var_P1 = var_P1 - 1,
                   var_T1 = var_T1 +1;

        };
}
```

Automated Verification of Workflow



NOVA Translator

Specification (System Property)

Reduced Model (System Requirements)

DiVinE(Model Checker)

Answer:

Yes, if the model satisfies the specification

Counterexample, otherwise

Correctness

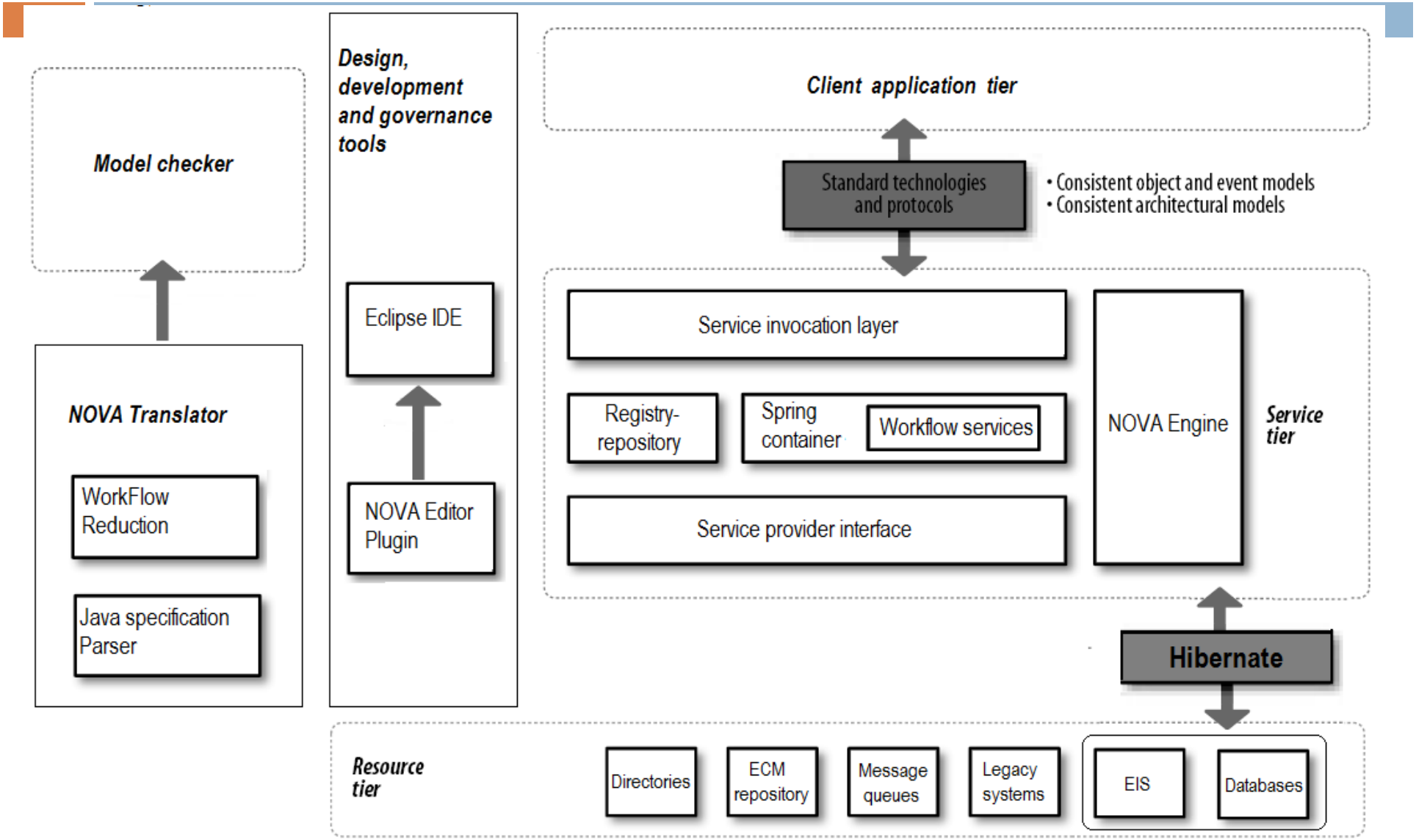
- Let F be an LTL formula, let PM be a Petri net model and let DM be its translation to DVE; then:

$$PN \models F \quad \text{iff} \quad DM \models F$$

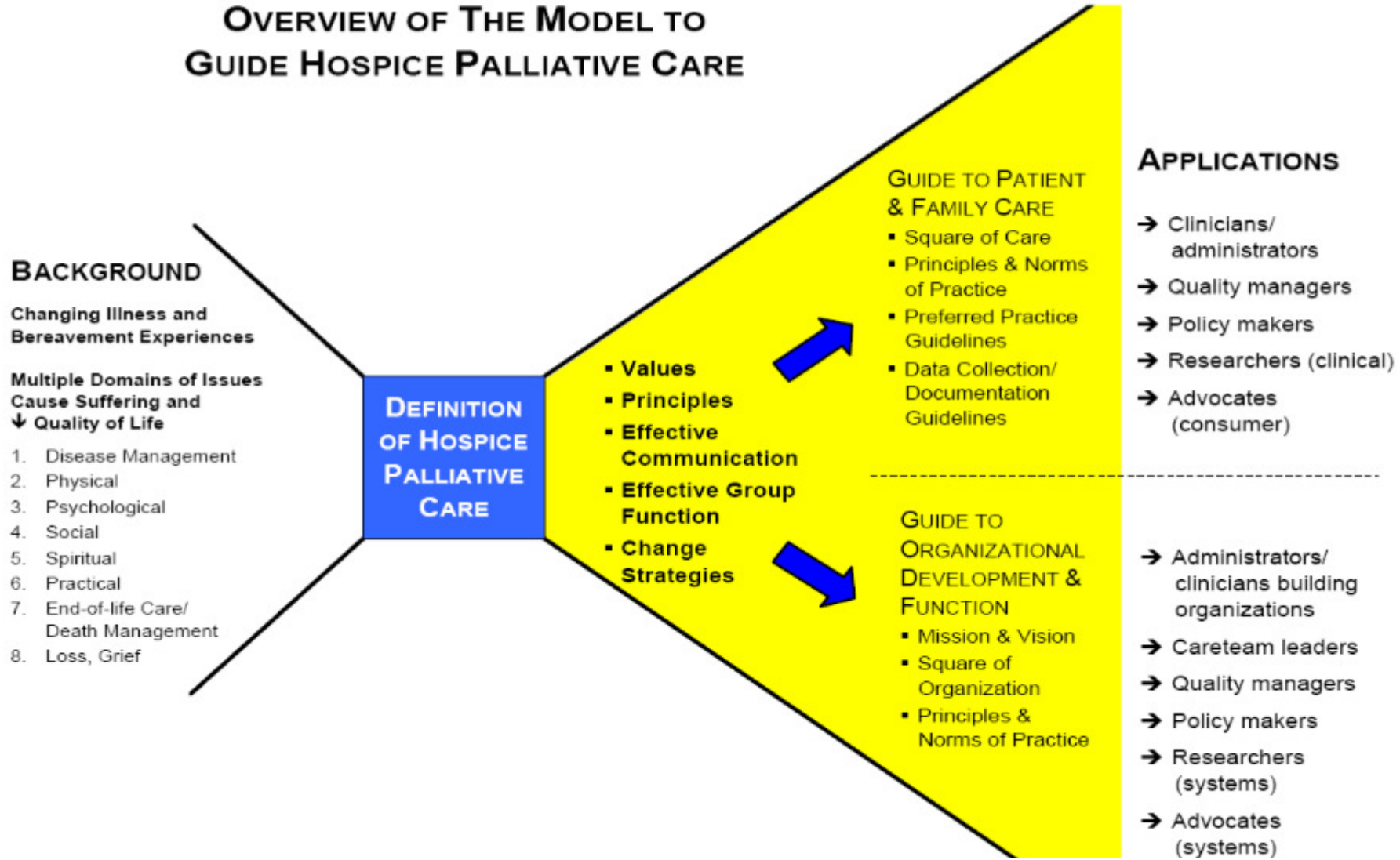
Let W be a workflow model and let W' be its reduction and let F an $LTL_{\_X}$ property; then

$$W \models F \quad \text{iff} \quad W' \models F$$

Nova Workflow Architecture

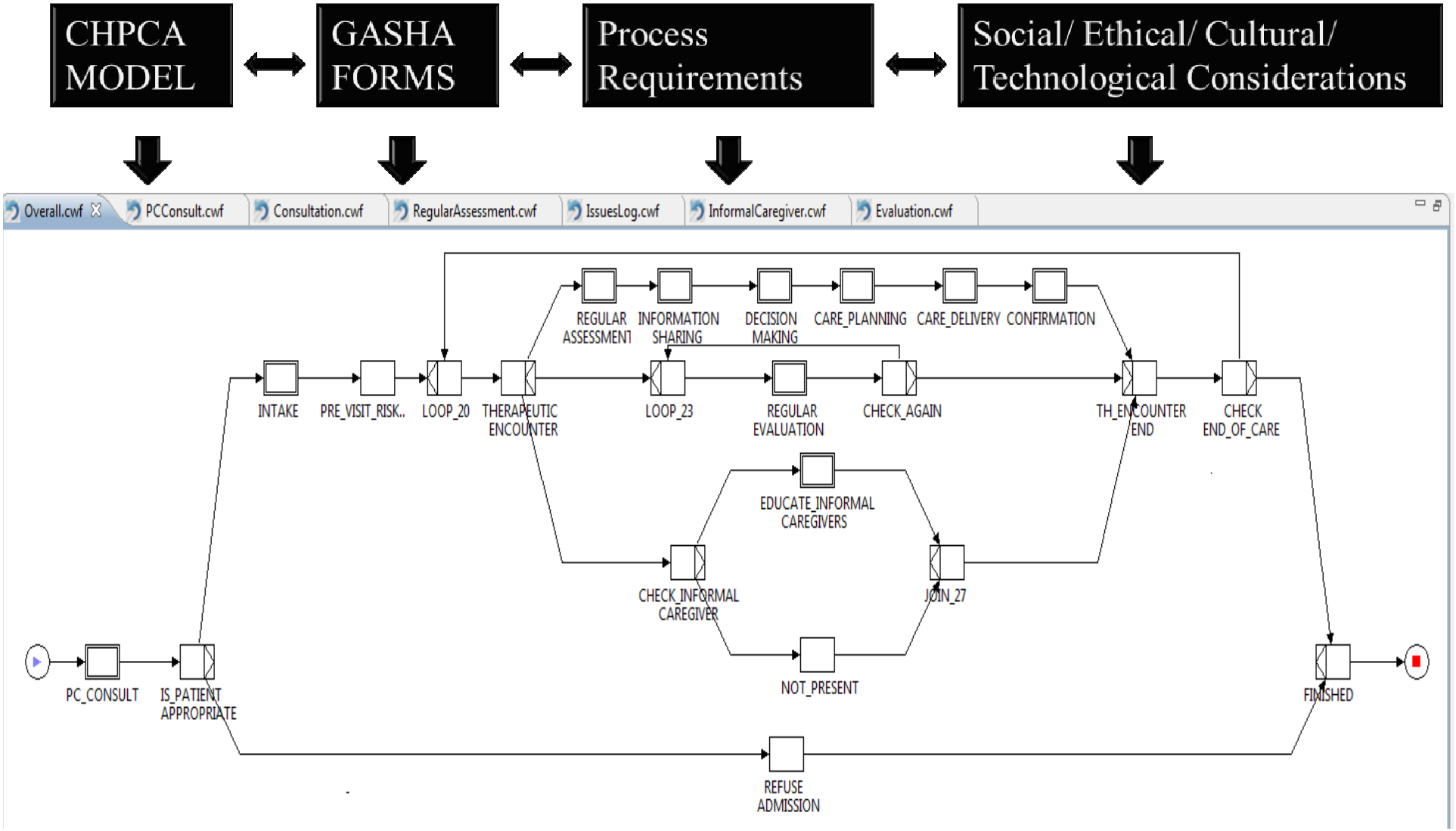


Case Study: 2002 National Model for HPC

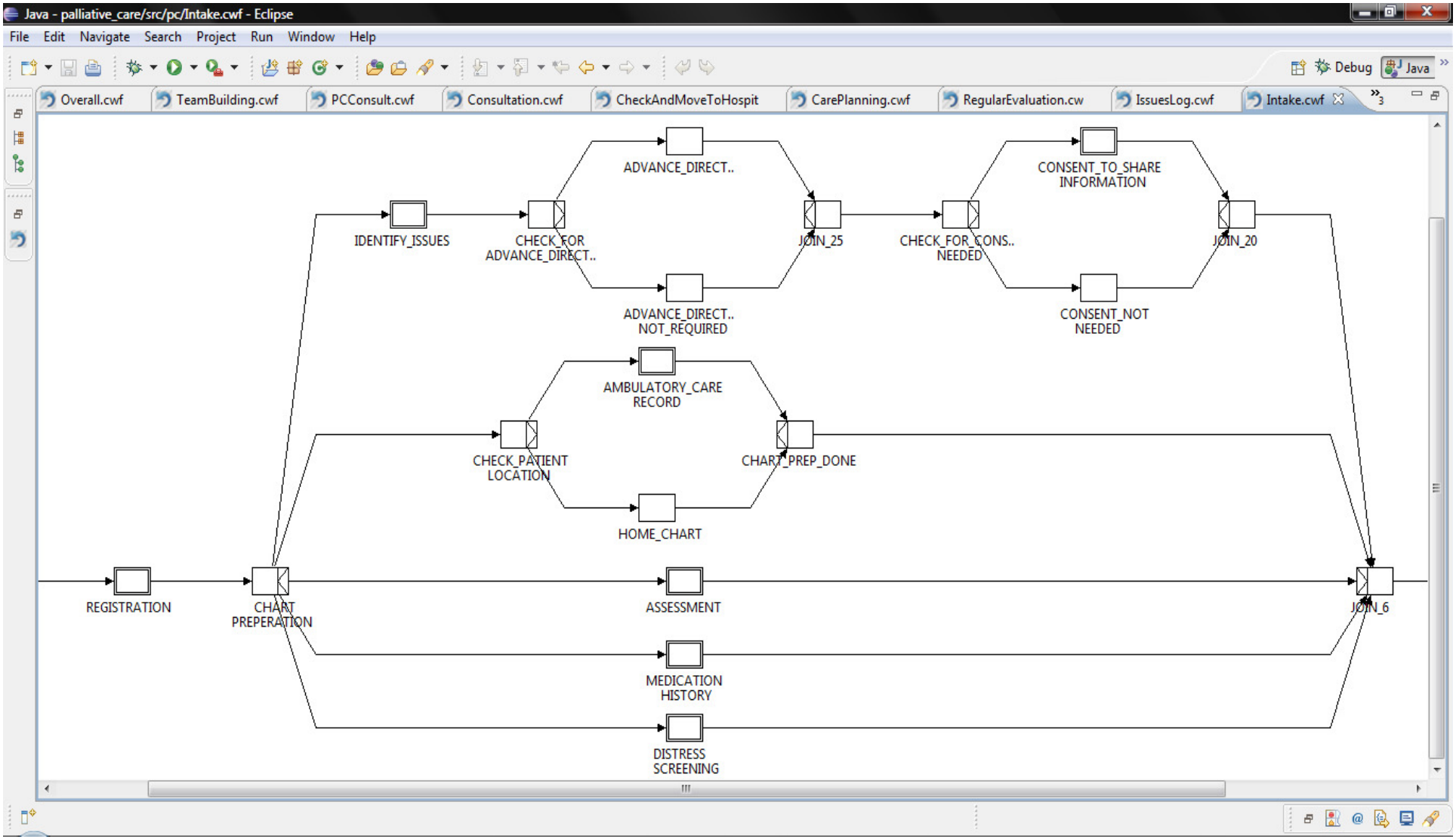


Palliative Care Workflow

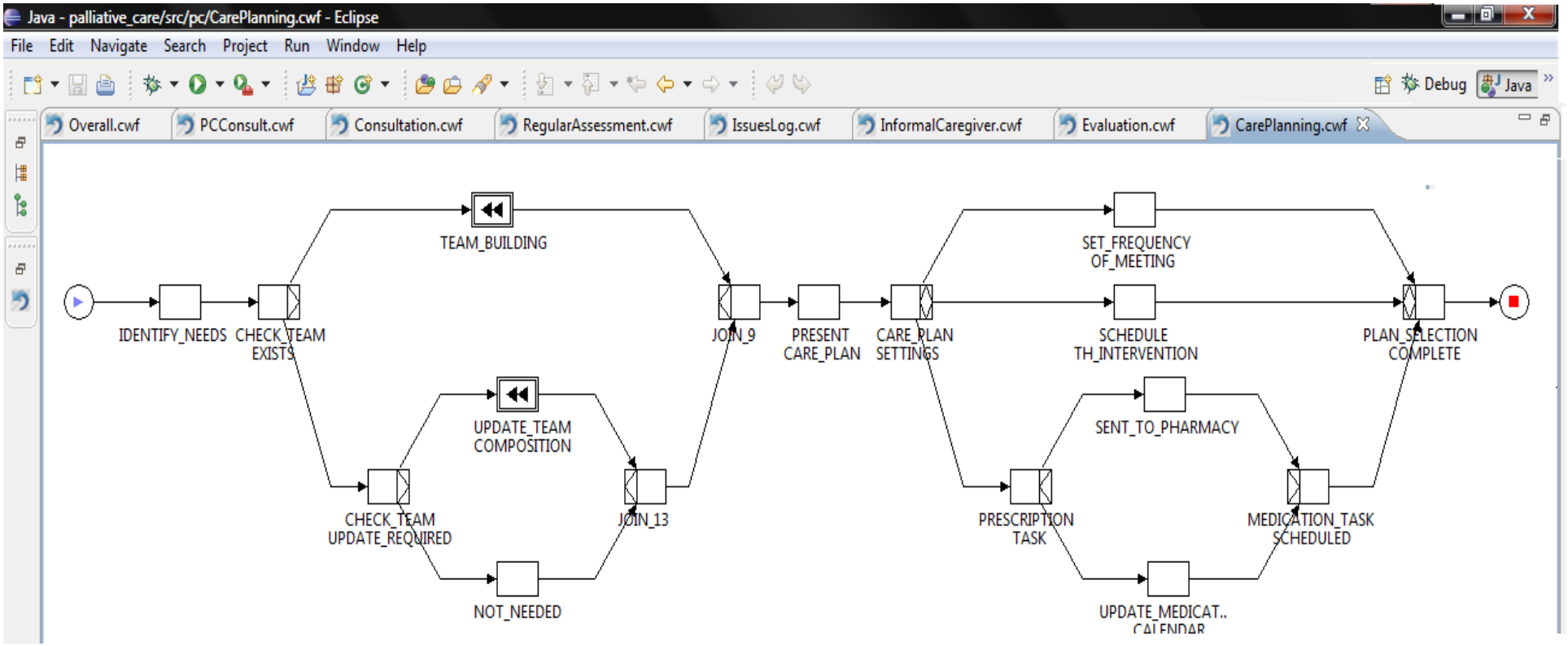
(150 unique tasks, 20 subnet flows, 40 decision points)

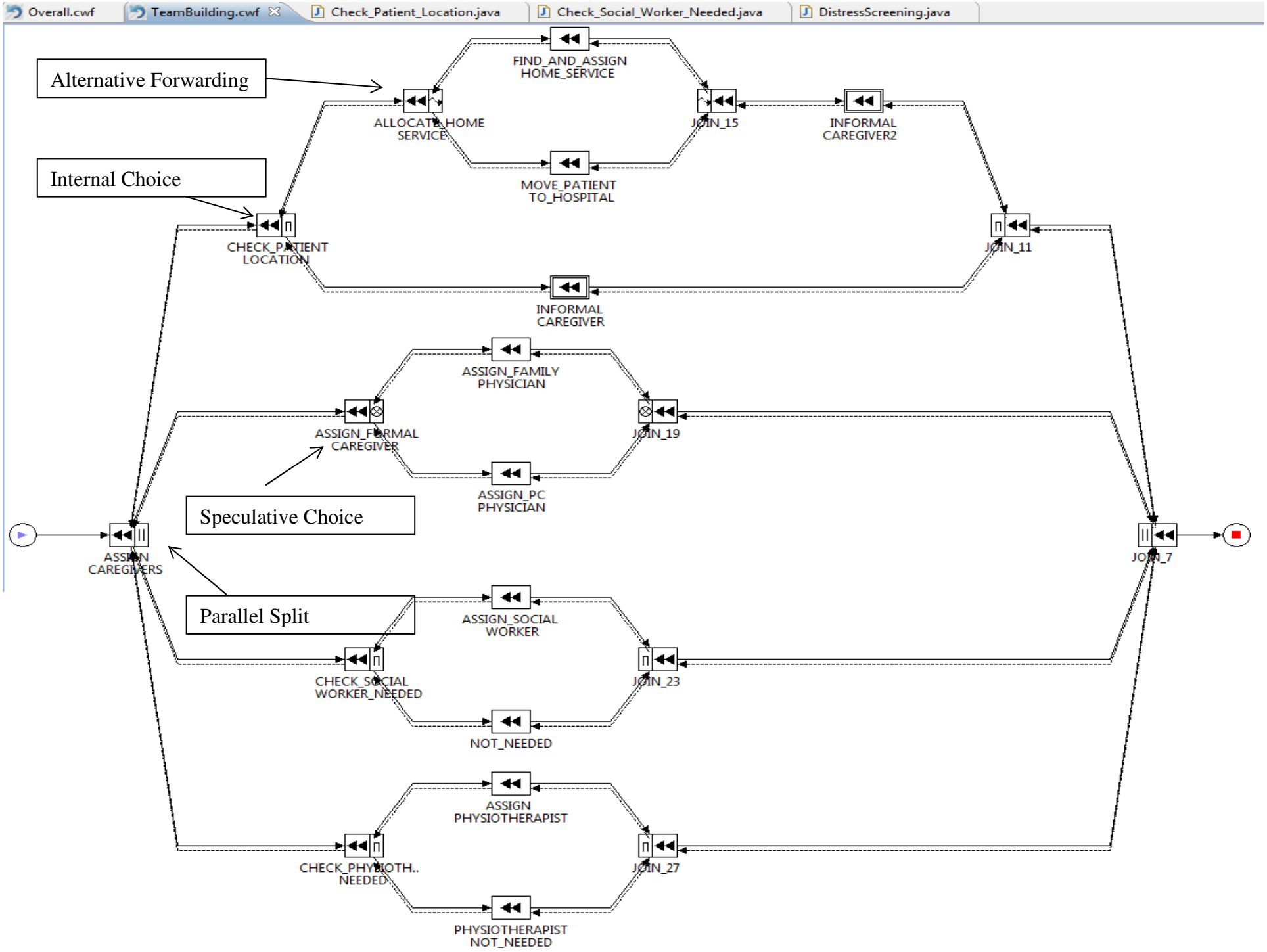


Intake


Java - palliative_care/src/pc/Intake.cwf - Eclipse
File Edit Navigate Search Project Run Window Help
Debug
Java
Overall.cwf
TeamBuilding.cwf
PCConsult.cwf
Consultation.cwf
CheckAndMoveToHospit
CarePlanning.cwf
RegularEvaluation.cw
IssuesLog.cwf
Intake.cwf
REGISTRATION
CHART PREPERATION
IDENTIFY_ISSUES
CHECK_FOR ADVANCE_DIRECT..
ADVANCE_DIRECT..
ADVANCE_DIRECT.. NOT_REQUIRED
JOIN_25
CHECK_FOR_CONS.. NEEDED
CONSENT_TO_SHARE INFORMATION
CONSENT_NOT NEEDED
JOIN_20
AMBULATORY_CARE RECORD
CHECK_PATIENT LOCATION
CHART_PREP_DONE
HOME_CHART
ASSESSMENT
MEDICATION HISTORY
DISTRESS SCREENING
JOIN_6

Care Planning




Overall.cwf
TeamBuilding.cwf
Check_Patient_Location.java
Check_Social_Worker_Needed.java
DistressScreening.java
Alternative Forwarding
Internal Choice
Speculative Choice
Parallel Split
FIND_AND_ASSIGN HOME_SERVICE
ALLOCATE_HOME SERVICE
JOIN_15
INFORMAL CAREGIVER2
MOVE_PATIENT TO_HOSPITAL
CHECK_PATIENT LOCATION
JOIN_11
INFORMAL CAREGIVER
ASSIGN_FAMILY PHYSICIAN
ASSIGN_FORMAL CAREGIVER
JOIN_19
ASSIGN_PC PHYSICIAN
ASSIGN CAREGIVERS
JOIN_7
ASSIGN_SOCIAL WORKER
CHECK_SOCIAL WORKER_NEEDED
JOIN_23
NOT_NEEDED
ASSIGN PHYSIOTHERAPIST
CHECK_PHYSIOTH.. NEEDED
JOIN_27
PHYSIOTHERAPIST NOT_NEEDED

Properties

- Norms -bgeneric principles of care meant to be interpreted locally
- Prop1 (N3.5, N4.1, N4.4, N5.3)- If patient is at home and has no family, then there must be a home service provided for his/her care. Otherwise, the patient must move to the hospital.
- Prop2 (N3.5, N4.1, N4.4)- If the patient is evaluated and assigned a PPS of 50% or lower then s/he must be moved to the hospital.
- Prop3 (N3.5, N4.1, N4.4)- If the patient is evaluated and assigned a level of 3 or lower on `Nursing Documentation' then s/he must be moved to the hospital.
- Prop4 (N5.1 N1.1, N1.3)- If the patient's mobility changes and is checked off in `Rounds Report', then a Physiotherapist will be notified.
- Prop5 (N2.1)- If the field ``Consent to Contact Other Team Member'' on `Issues Log' is set to YES, then Consent to Share Information must be filled out.

Verification Results

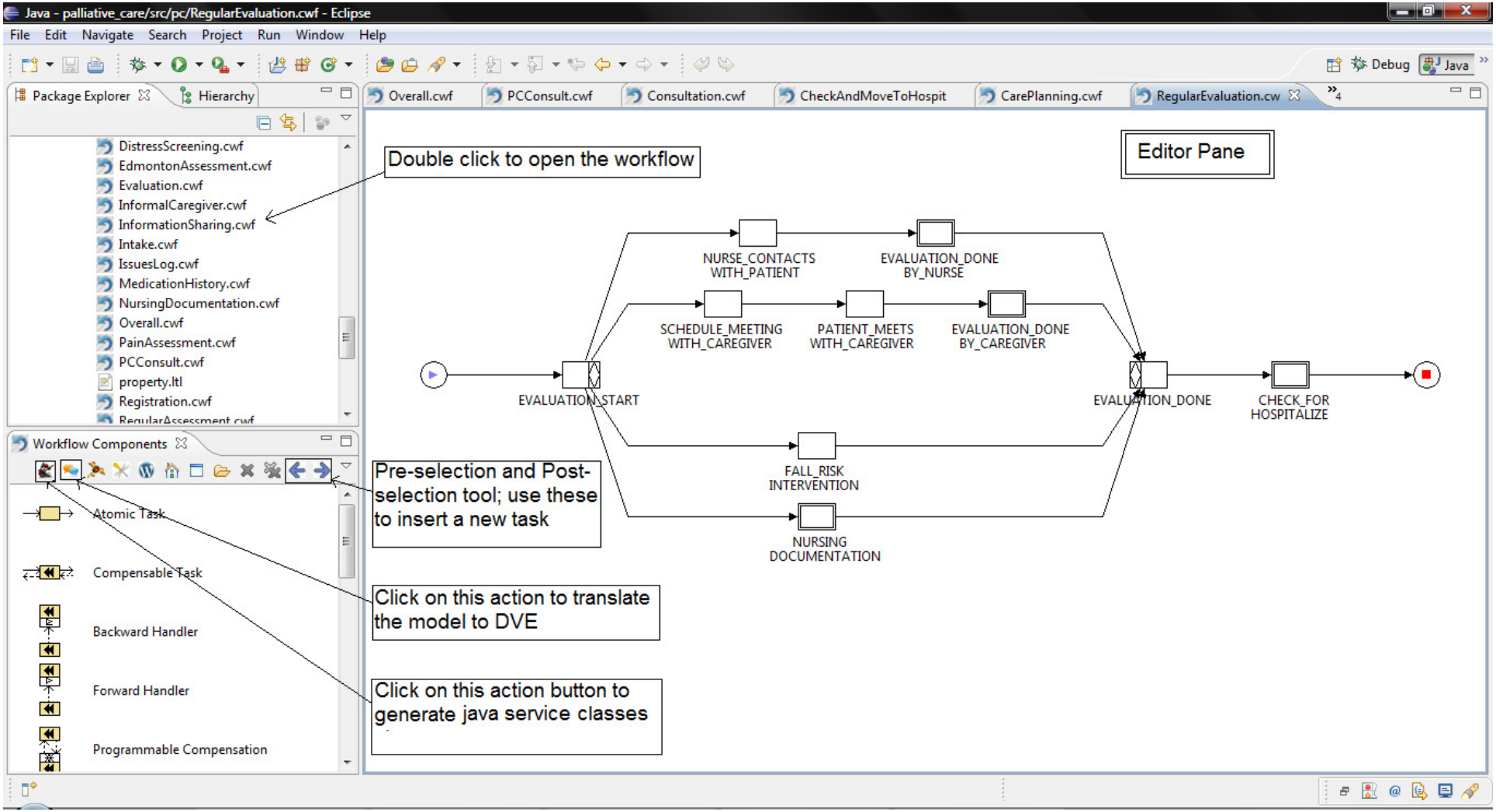
Property	Accepting Cycle	States	Memory (MB)	Time (s)
Prop1	No	126188210	88619.1	454.4
Prop2	No	128013744	88920.0	397.9
Prop3	No	127934841	88894	396.1
Prop4	No	132038485	90285.3	315.0
Prop5	No	119611390	85030.1	359.7

All experiments were executed on the Mahone2 cluster of ACEnet, the high performance computing consortium for universities in Atlantic Canada. The tests were performed using DiVinE with 64 CPU's and 3G v memCPU.

Comparison with other tools

Feature	YAWL	ADEPT2	IBM (WebSphere Product Line)	NOVA WorkFlow
Modeling Language	Unstructured	Structured	Unstructured	Structured
Workflow Patterns	Yes (most)	Not all	Not all	Not all
Compensation	No	No	Yes (some)	Yes
LTL-Verification	No	No	No	Yes
Collaborative Development	No	Yes	Yes	Yes
Default Form for Simulation	Yes	Yes	Yes	No
Dynamic change during execution	No	Yes	Yes	No
Language Support	XML, XQuery	Java	BPEL, XPDL, Java	Java
Web Service Integration	Yes	Yes	Yes	Yes

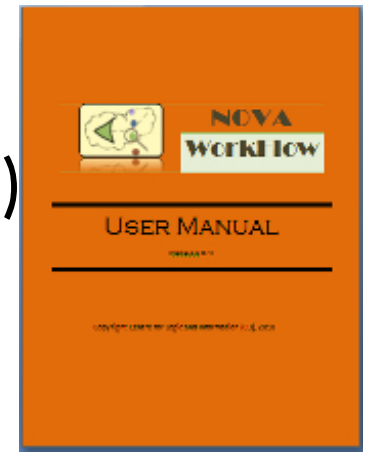
Graphical Editor: Regular Evaluation



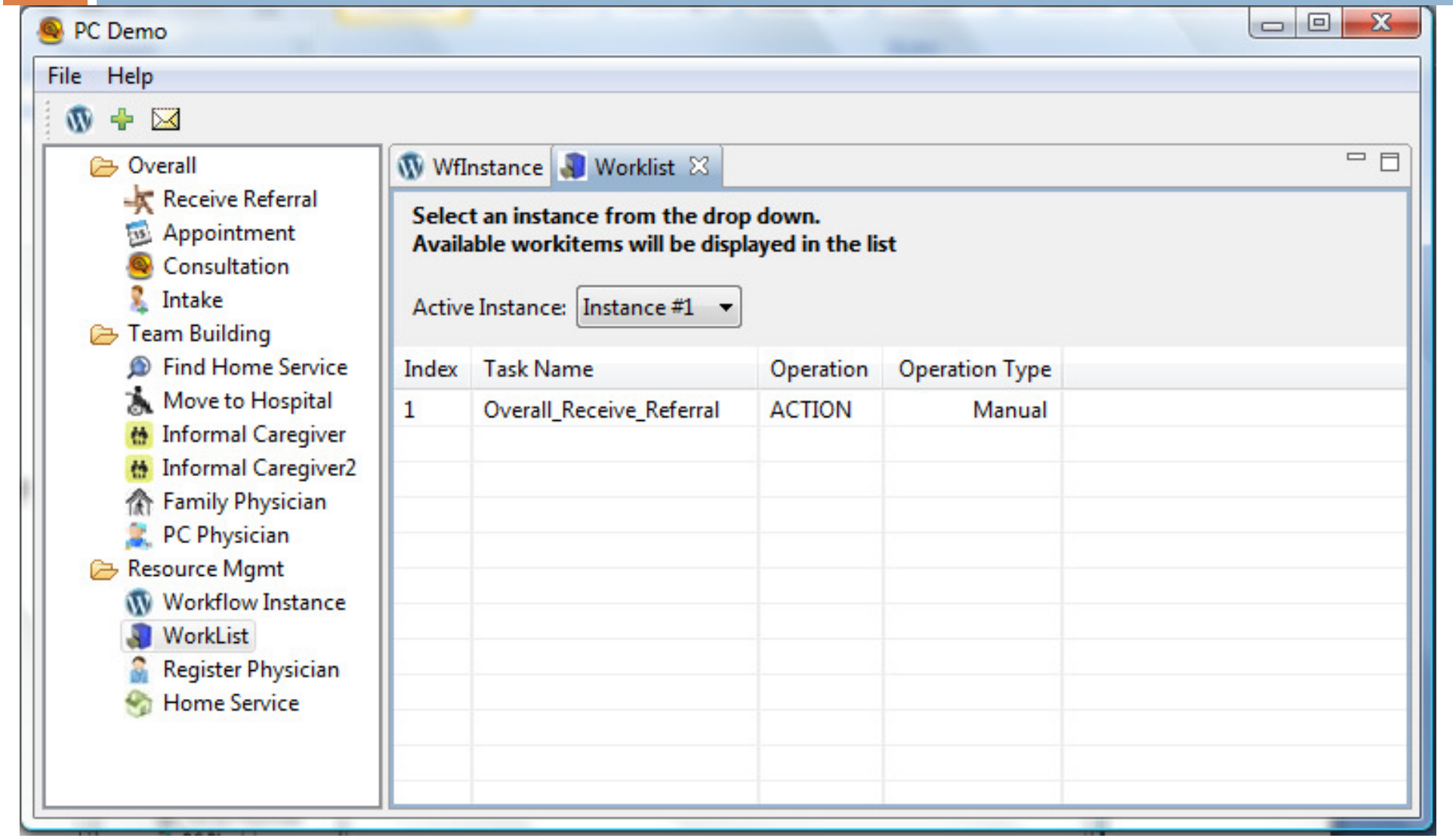
Workflow Execution

- NOVA Workflow generates Java code;
- The user provides details of the implementations for the specific task; that is, business logics;
- NOVA Workflow engine executes these tasks in a web server (such as websphere, tomcat, etc)

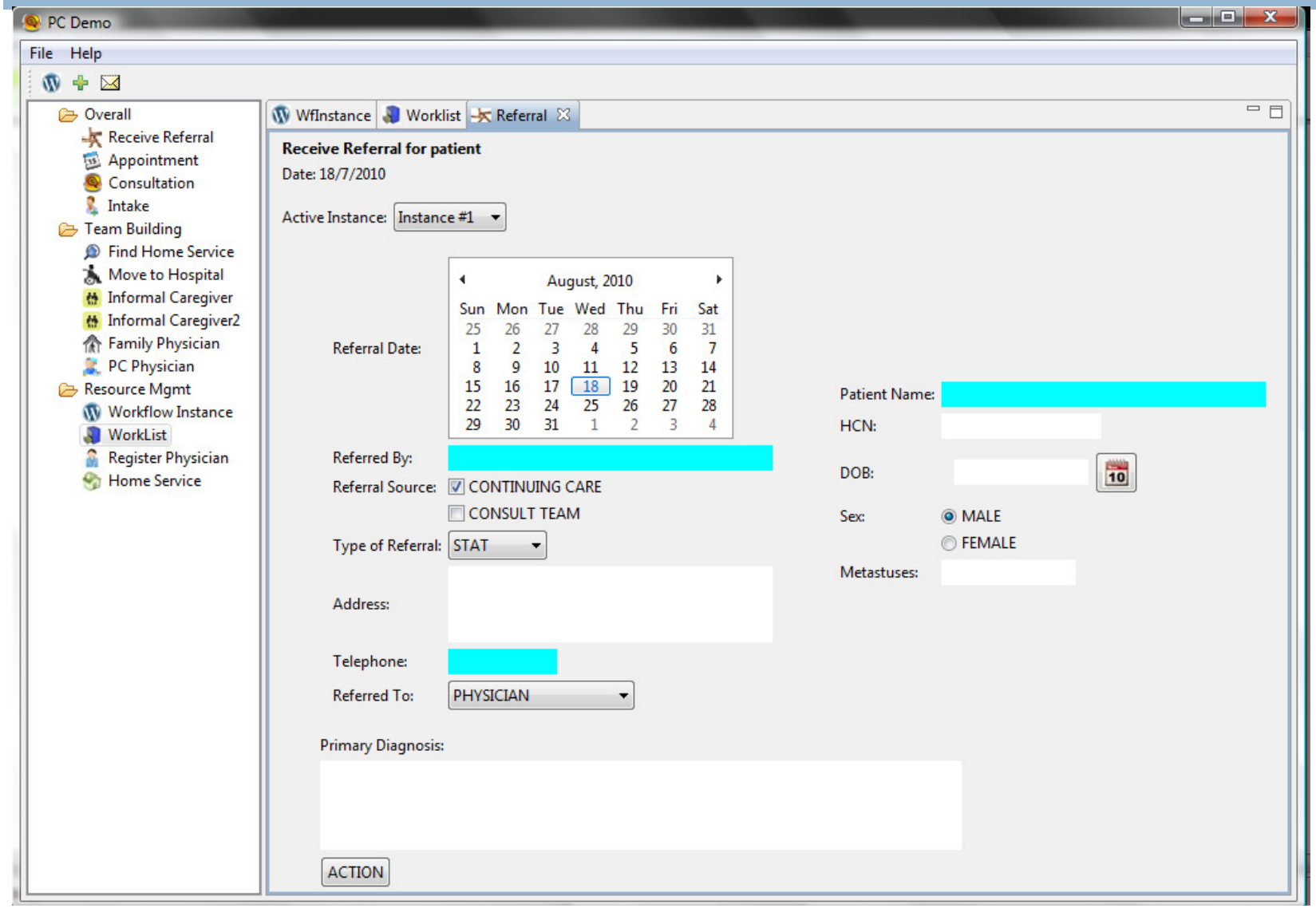
Visit CLI website (user manual, examples, etc.)



Client Application that communicates with Nova Workflow Engine



Client Application ctd.



Ongoing Research:

- Incorporate Time into CWML
- Ontology Integration with NOVA Workflow
- Personalized access control framework for workflow based healthcare information.
- Scheduling and Monitoring healthcare processes
- Default Forms for Simulation
- Dynamic Change of Workflow Schema

References

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- F.Rabbi, H.Wang and W.MacCaull, *Compensable WorkFlow Nets*. 12th International Conference on Formal Engineering Methods (ICFEM 2010), (Nov. 2010), to appear.
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