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University of Cyprus

MAI643 Artificial Intelligence in Medicine

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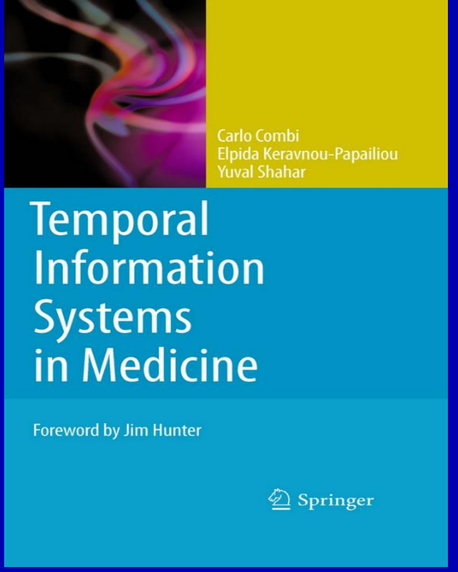

Automated Support to Clinical Guidelines and Care Plans

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UNIT 11

Automated Support to Clinical Guidelines and Care Plans

CONTENTS

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INTENDED LEARNING OUTCOMES

Upon completion of this unit on automated support to clinical guidelines and care plans, students will be able:

1. To explain what a clinical guideline, or care plan, is.
2. To appreciate the need for automated-support in facilitating the dissemination and application of clinical guidelines and why synergy is the key word.
3. To list the tasks involved in guideline-based care and the different approaches to guideline automation.
4. To overview a number of specific approaches for the automation of complex, longitudinal, guideline-based care (EON project, PROforma methodology, GLIF ontology, Prodigy project, GUIDE project).
5. To present the Asgaard project and the Asbru language.
6. Likewise to present the hybrid guideline representation proposed in the DeGeL project and the guideline conversion process involved.
7. Overall, to argue for the importance of clinical guidelines and what their effective application in a clinical context entails.

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Clinical Guidelines: an Introduction

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Clinical Guidelines

- **Clinical guidelines** (sometimes referred as **Care Plans**) are a powerful method for standardization and uniform improvement of the quality of medical care.

- They are developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances.

- The application of clinical guidelines typically involves collecting and interpreting considerable amounts of data over time
  - reasoning about time-oriented data and actions is essential for guideline-base care

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Clinical Guidelines

Clinical guidelines can be viewed as:

- reusable **skeletal plans**: a set of plans at varying levels of abstraction and detail that need to be refined by a care provider over significant time period.

- a set of **constraints**, mostly temporal, regarding the process of applying the guideline and its desired outcomes.

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The Need for Automated-Support

- Most clinical guidelines are text-based.
- Even when guidelines exist in electronic format, physicians rarely have the time and means to decide which of the multiple guidelines best pertains to their patient.
- Due to the limitations of state-of-art technologies, analyzing unstructured text-based guidelines is not feasible.
- Hence there is an urgent need to facilitate guideline dissemination and application using machine-readable representations and automated computational methods.

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The Need for Automated-Support

Supporting guideline-based care implies creation of a **dialogue between a care provider and an automated support system**:

- Physicians have better access to certain types of patient-specific clinical information and to general medical and commonsense knowledge.
- Automated systems have better and more accurate access to guideline specifications and detect more easily pre-specified complex temporal patterns in patient's data.

Key word is synergy.

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Tasks involved in guideline-based care

Task	*Questions to be answered*	*Required Knowledge*
Verification of a guideline	Are the intended plans, or processes (potentially) achievable by following the prescribed *actions*? (*a syntactic check*)	Prescribed actions; intended overall action pattern (i.e., the intended plan, or process)
Validation of a guideline	Are the intended *outcomes* (potentially) achievable by the prescribed *actions* and intended *plan*? (*a semantic check*)	Prescribed actions, intended overall action pattern (process); intended outcomes; action/plan effects
Applicability of guidelines	What guidelines or protocols are applicable at this time to this patient?	Filter and setup preconditions; overall intended outcomes; the patient's state
Eligibility of patients	Which patients are currently eligible for the given guideline?	Filter and setup preconditions; overall intended outcomes; the patients states
Application of a guideline	What should be done at this time according to the guideline's prescribed actions?	Prescribed actions and their filter and setup preconditions; suspension, restart, completion, and abort conditions; the patient's state

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Tasks involved in guideline-based care (cont.)

Task	*Questions to be answered*	*Required Knowledge*
Recognition of the care-provider's intentions	Why is the care provider executing a particular set of actions, especially if those deviate from the guideline's prescribed actions?	Executed actions and their abstraction to executed plans; process and outcome intentions; the patient's state; action/plan effects; revision strategies; preferences
Quality assessment	Is the care provider deviating from the prescribed actions or intended plan? Are the deviating actions compatible with the author's plan and state intentions?	Executed actions and their abstraction to plans; action and state intentions of the original plan; the patient's state; action/plan effects; revision strategies; preferences
Evaluation of a guideline	Is the guideline working?	Intermediate/overall outcome intentions; the patient's state; intermediate/overall process intentions; executed actions and plans
Modification of a potential (candidate) or currently running (being applied) guideline or action	What alternative guidelines or actions are relevant at this time for achieving a given outcome or process intention?	Intermediate/overall outcome intentions; action/plan effects; filter and setup preconditions; revision strategies; preferences; the patient's state

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Automation of Clinical Guidelines

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Automation of Clinical Guidelines

- Several approaches permit hypertext browsing of guidelines via the World Wide Web but do not directly use the patient's electronic medical record.

- Approaches that do use the patient's data encode guidelines as elementary state-transition tables or as situation-action rules dependent on the electronic medical record.

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Prescriptive versus Critiquing Approaches

- **Prescriptive Approaches**: specifying what actions need to be performed and how.
- **Critiquing Approaches**: the physician suggests a specific therapy plan and gets feedback from the program. System output is focused on the user's input plan and directly relevant to it.

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The Arden Syntax

The Arden Syntax represents medical knowledge as independent units called **Medical Logical Modules (MLMs),** which use a Pascal-like programming language to encode highly specific rules, grounded in the local institution's database schema.

The curly brackets problem:
Enclosing in curly braces terms that need to be replaced by local terms (in the general medical logic), then substituting them at implementation time.

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An MLM Example

- **Maintenance:**
  - title: Agranulocytosis and trimethoprim/sulfamethoxazole
  - author: Dr. Bonzo
- **Library:**
  - keywords: granulocytopenia; agranulocytosis; trimethoprim; sulfamethoxazole
  - citations: 1. Anti-infective drug use ... Archives of Internal Medicine 1989; 149(5): 1036-40
- **Knowledge:**
  - type: data driven;
  - data:
    - anc:= read last 2 from ({query for ANC} where it occurred within the past 1 week);
    - pt_taking_tms := read exist {query for TMS order};
    - evoke: on storage of {ANC};
  - logic:
    - if pt_taking_tms and last anc < 1000 and decrease of anc > 0 then conclude true else conclude false;
  - action:
    - store “Caution: The patient’s relative granulocytopenia may be exacerbated by trimethoprim/sulfamethoxazole.”;

Issues

- Difficulty in reuse of general clinical knowledge within different context, even within a single system.
- Sharing problems: most of the difficulties were due to local query and vocabulary differences as well as local practices.
- Difficulty in representation of continuous therapy plans: each MLM represent a well-defined, independent rule, not suitable for representing a long-term therapy plan.
- Lack of ability to represent and reuse higher, meta-level problem-solving knowledge.
- Lack of explicit notification mechanisms for alerts and reminders; notification is contained in curly braces in an MLM and left to local implementers.

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Automation of Complex, Longitudinal, Guideline-Based Care

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Automation of complex, longitudinal, guideline-based care

During the past 30 years, there have been several efforts to support complex guideline-based care over time in automated fashion.

A brief summary of several of the influential architectures and representation languages follows.

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The EON Project

- The **EON Project** is a general, client-server architecture that developers can use to build systems that support automated reasoning about guideline-directed care.

- The EON framework has gradually evolved from Stanford University's domain-specific ONCOCIN project (oncology protocols at Stanford lymphoma clinic) and T-HELPER project (encoded and applied to therapeutic and prophylactic guidelines in the AIDS domain)

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The EON Framework

The EON framework includes reusable problem-solving components that have specific functions, such as:

- **A therapy planner**, based on a version of the *episodic skeletal-plan-refinement* problem-solving method.

- **A temporal mediator**, which can answer queries to a patient database about either primitive time-oriented patient data or their abstractions. The mediator includes two components:
  - the RASTA temporal abstraction module;
  - the Chronus-II temporal-maintenance system

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The EON Framework (cont.)

- An **eligibility-determination module**, **Yenta**, which matches patients and their characteristics to eligibility criteria of clinical guidelines.

- A **knowledge-acquisition module** to acquire and maintain clinical guidelines. The module was designed by using tools from the Protégé project, it focuses on automated generation of graphical knowledge-acquisition tools, given the ontology of the problem-solving method.

- A shared knowledge base, maintained by the Protégé-based knowledge-acquisition module, of clinical guidelines and general medical concepts.

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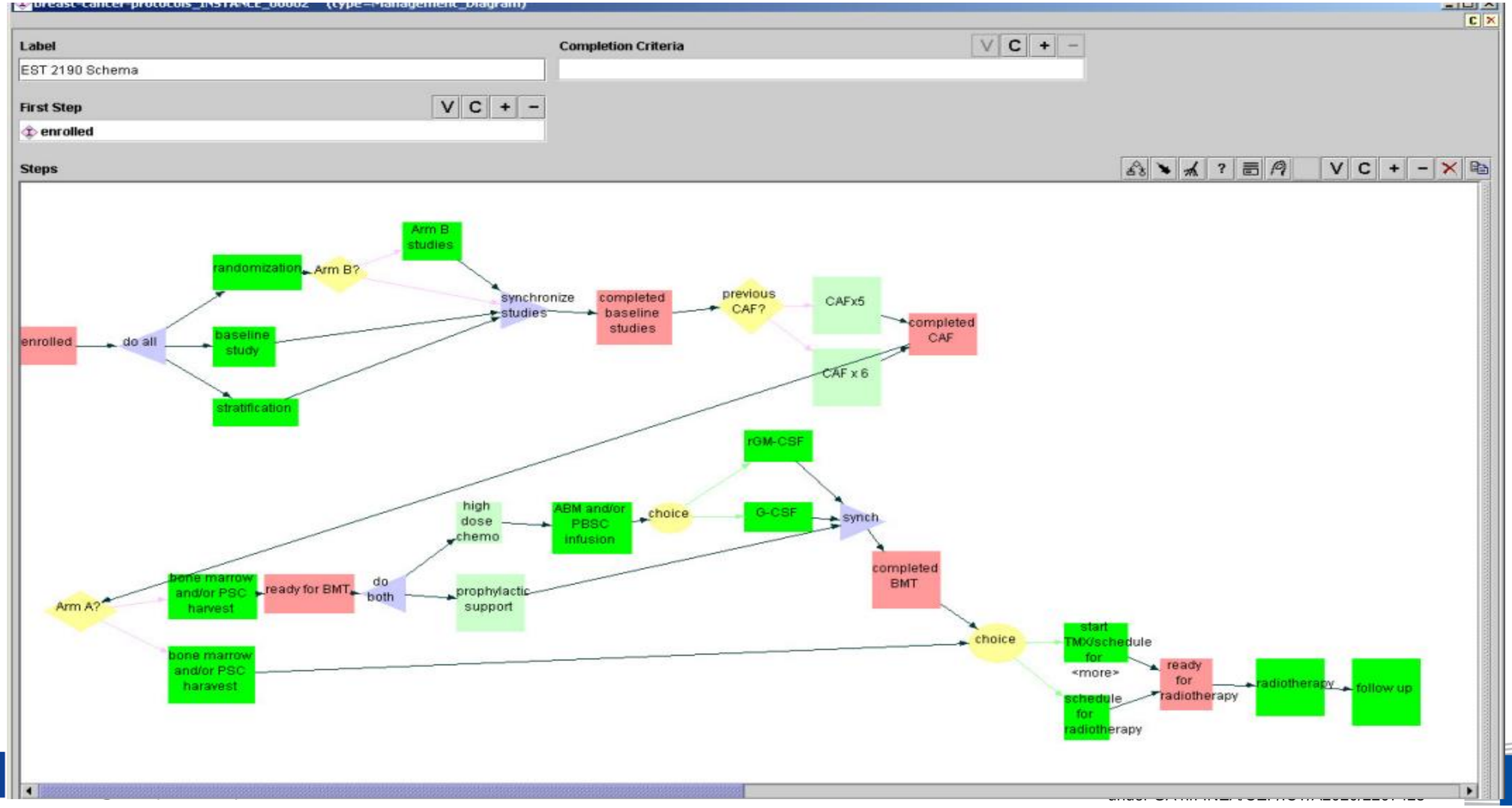
Graphical interface generated by Protégé-2000



EON Architecture: ATHENA

- A specific successful instance of the EON architecture is the **ATHENA system** for management of hypertension.

- The knowledge base includes eligibility criteria, risk stratification, blood pressure targets, relevant comorbid diseases, guideline-recommended drug class or individual drugs for patient with comorbid disease, preferred drugs within each drug class, and clinical messages.

- ATHENA uses the clinical temporal database mediator **Athenaeum** to access patient data.

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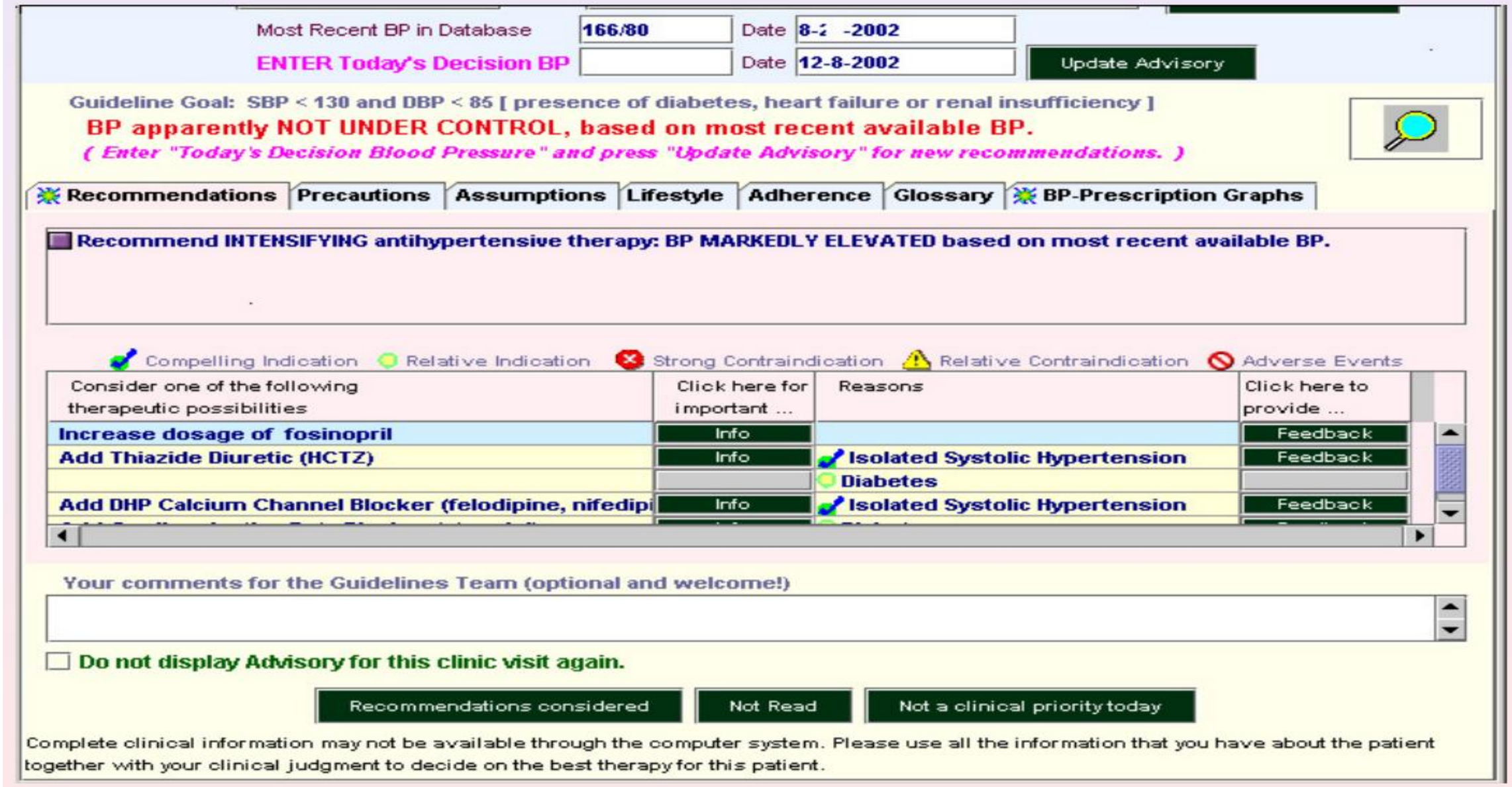
EON Architecture: ATHENA



The PROforma Methodology

- The **PROforma** framework was developed at the Advanced Computation Laboratory (ACL) of Cancer Research UK.

- The basic modeling approach integrates object-oriented and logic programming techniques. The PROforma approach explores the expressiveness of an intentionally minimal set of constructs: Plans, Actions, Decision and Enquiries.
  - All tasks inherit the generic attributes name, caption, description, goals, preconditions, trigger conditions and postconditions.
  - Further attributes of the four task subclasses are specific to that subclass and are only inherited by tasks of that subclass type.

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The PROforma Methodology

- PROforma supports the definition of clinical guidelines and protocols in terms of a set of tasks that can be composed into networks representing plans or procedures carried out over time.

- A graphical editor for PROforma guidelines has been developed and PROforma applications demonstrating guideline enactment over the World Wide Web are currently under development.

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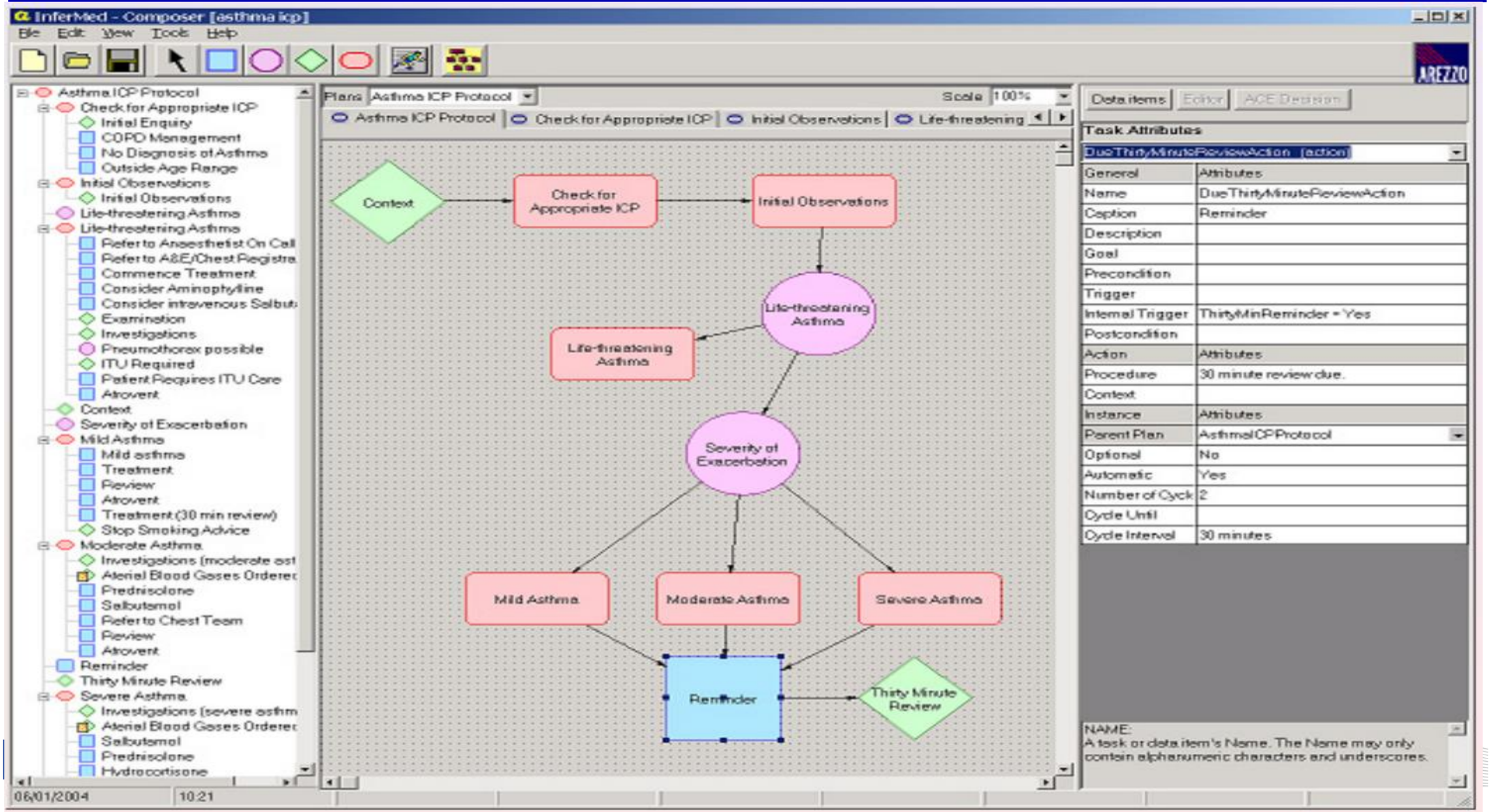
A graphical editor for PROforma



The Guideline Interchange Format (GLIF)

- The **GLIF ontology** attempted to integrate key lessons from Arden syntax and MLMs, the EON project, the Asgaard project and the Asbru language, and other guidelines-representation projects.

- The current core language, **GLIF-3**, includes several core ontological entities in the contest of flowchart.

- The GLIF default medical data model is based on the HL7 **reference information model (RIM)**. GLIF includes a formal syntax for querying about patient state.

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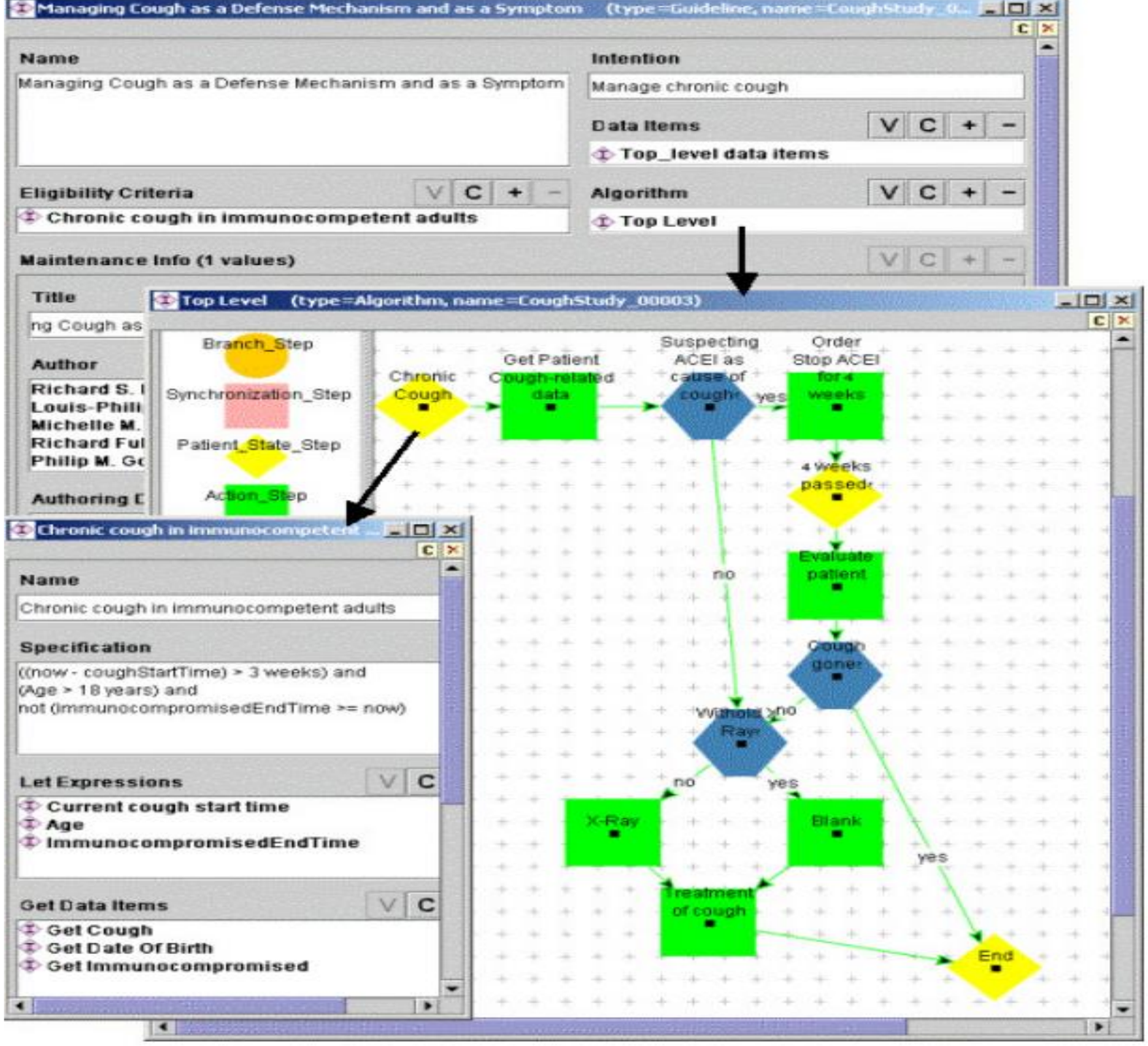

GLIF: Cough management guideline by Protégé-2000

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The Guideline Interchange Format (GLIF)

- GLIF can represent **temporal operators** from the Arden syntax, but not complex temporal expressions or temporal abstractions.

- An example of using the earlier GLIF-2 ontology for representation of complex clinical guidelines was reported by the Boston-based Partner's Healthcare System. The team encoded the secondary prevention portion of the National Cholesterol Education Program (PCAPE).

- The major obstacle: integrating the system into the clinical workflow; without more sophisticated methods for such integration the benefits will be small.

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The British Prodigy Project

The **British Prodigy project** has benefited from the earlier British DILEMMA project and the European PRESTIGE project: complex clinical guidelines over time:

- ❑ focuses on primary-care management of major chronic diseases (hypertension, coronary heart disease, diabetes and asthma).
- ❑ uses the Protégé set of tools to acquire and represent a set of clinical guidelines.

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The British Prodigy Project: structure

- A key knowledge structure in the Prodigy framework is the **scenario**, which defines a particular clinical context, or patient state.
  - supports the creation of multiple, explicit entry points into the guideline, especially when patients might return in the future in a different state.
- The Prodigy architecture uses a **virtual medical record** model to link a specific patient record structure.

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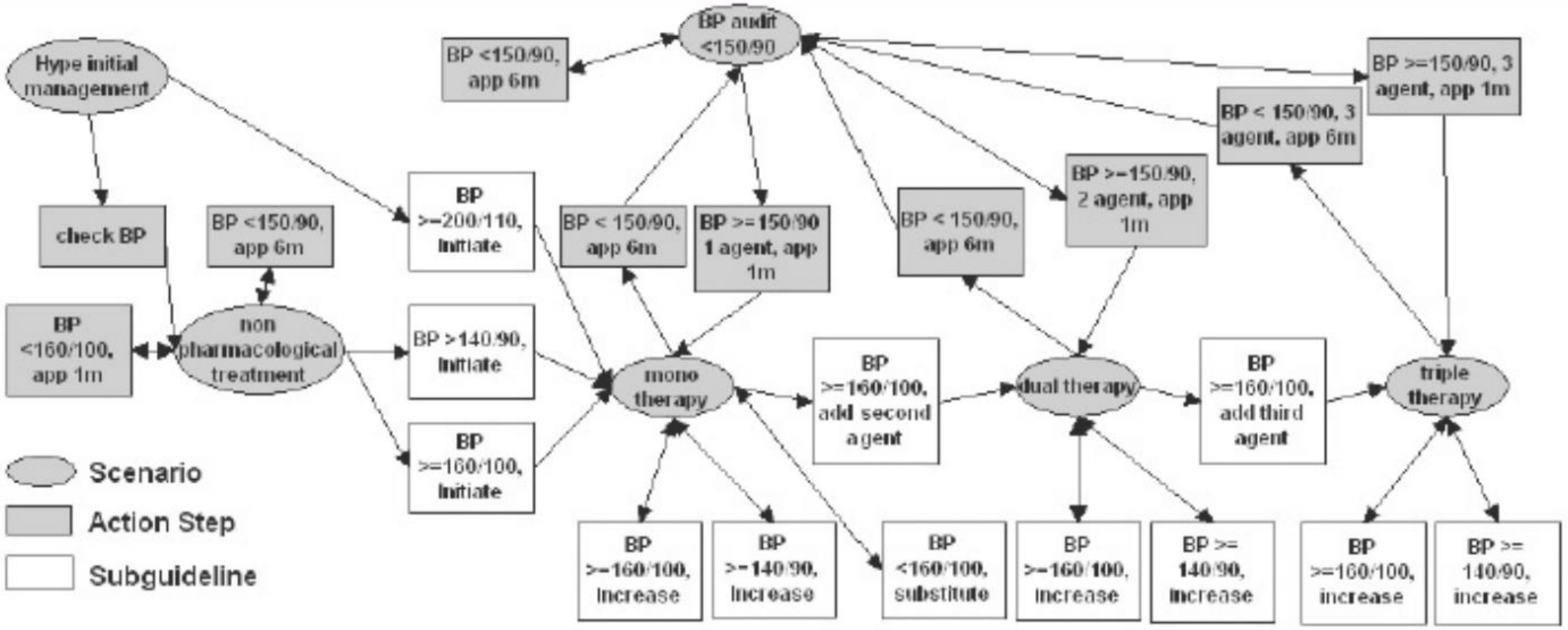
Clinical scenario in the Prodigy Project



The Italian GUIDE Project

The **GUIDE project** is part of a more general framework, Careflow, developed at the University of Pavia, Italy, for modeling and applying clinical guidelines in the broader context of general medical care.

The GUIDE framework focuses on two important aspects:

- the integration of guidelines into organizational workflow;
- supporting the use of decision-analytical models (decision trees, influence diagrams) in addition to standard procedural models.

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The Italian GUIDE Project

- The underlying guideline representation in the GUIDE framework uses the **Petri Net** formalism for modeling concurrent processes.
  - has extended Petri Nets to support improved modeling of time, data and plan hierarchies.

- The graphical GUIDE authoring tool enables designers to interactively author a guideline flowchart as Petri Net. Computational tools enable simulation of the resulting guideline using the Petri Net semantics.

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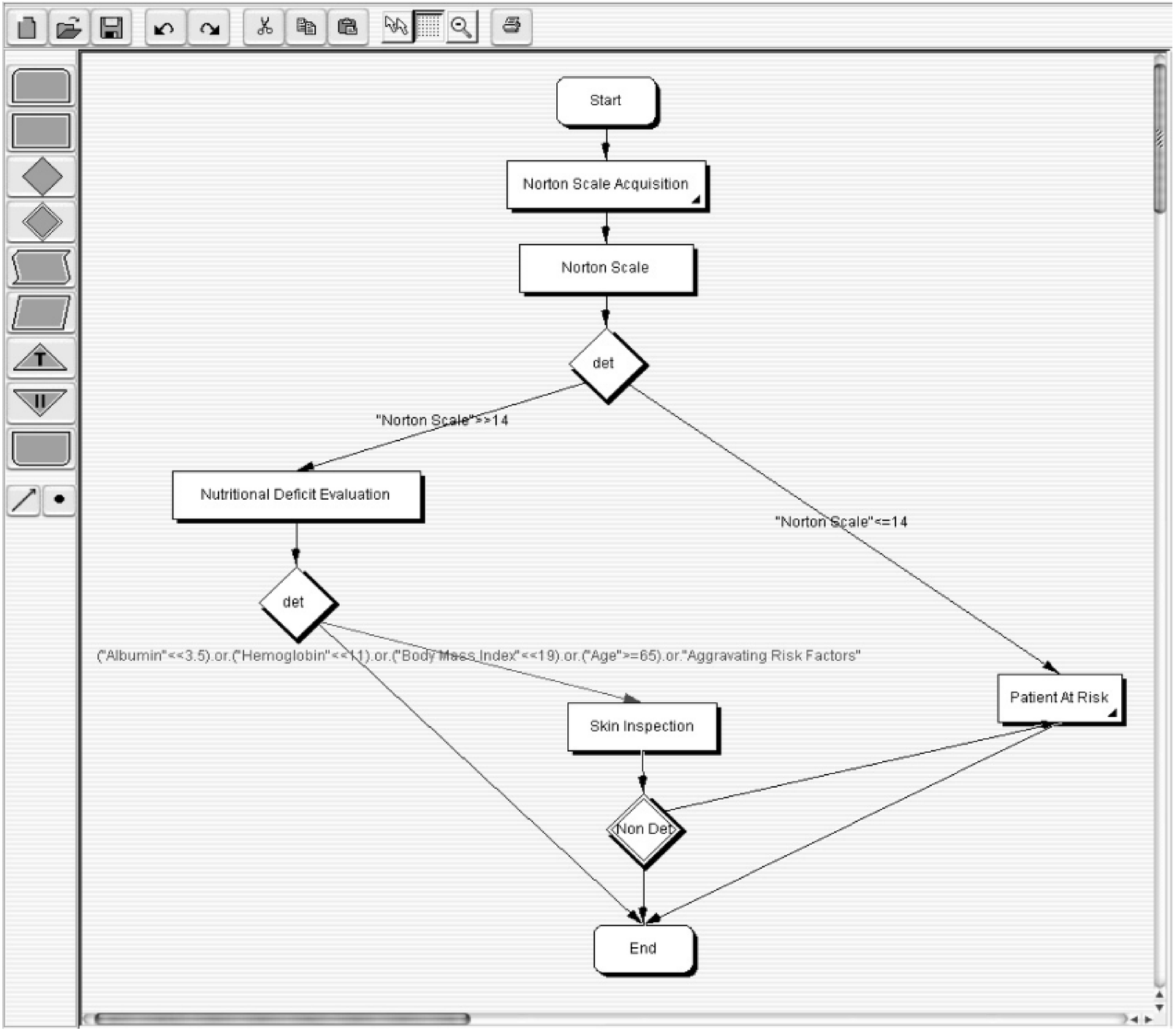

Graphical GUIDE authoring tool

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The Asgaard Project and the Asbru Language

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The Asgaard Project and the Asbru Language

The research over the past two decades at least has demonstrate that automating complex guideline-based care requires the use of:

- an underlying richly expressive, machine-readable formal language,
- specific to that task,
- which enables specification of multiple types of clinical actions over time,
- associated temporal and other constraints,
- the intermediate and overall clinical-processes and patient-outcome goals of the therapy plan.

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The Asgaard Project and the Asbru Language

- Last point relates to the **process** and **outcome intentions** of the **guideline**, or the physician **action** and patient **state** intentions of the guideline.
- These intentions are in fact **temporal-pattern constraints** that have individual **weights** signifying their relative importance.
- The intention-oriented language **Asbru**, had been designed within the Asgaard project.

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The Design-Time versus the Execution-Time of an Intention-Based Model

The Asgaard project is underlined by a set of basic assumptions regarding the typical scenario involved in specification and application of clinical guidelines.

During **design time** of a clinical guideline, an author designs a guideline and prescribes:

- actions,
- an intended plan,
- the intended intermediate and overall pattern of patient states or outcomes.

During **execution time**,

- A care provider applies the guideline by performing actions, which are recorded, observed, and abstracted over time.
- The state of the patient also is recorded, observed and abstracted over time.
- The intentions of the care provider might be recorded too-inferred from her actions or explicitly stated by the provider.

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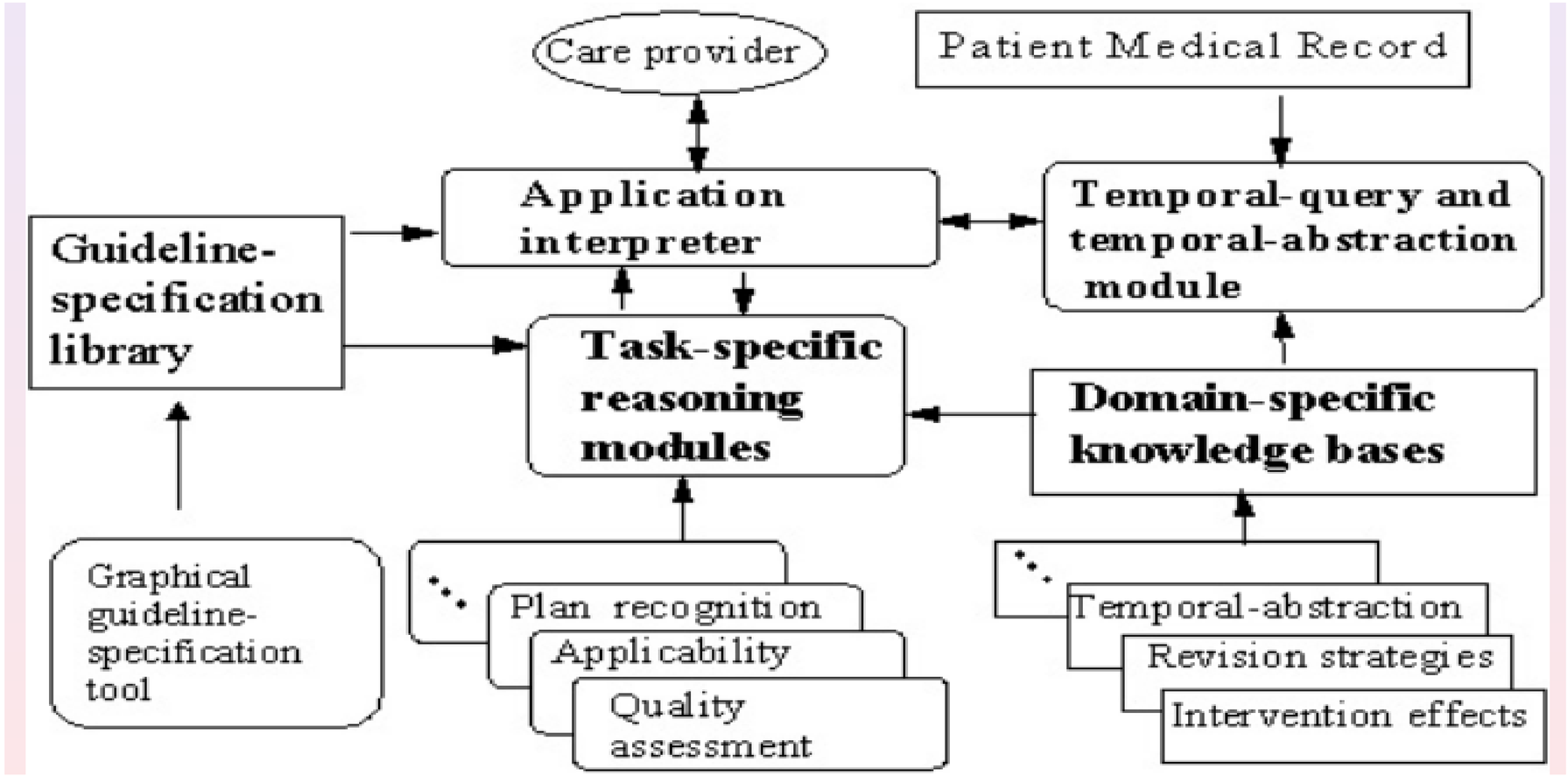
The Asgaard guideline-support environment



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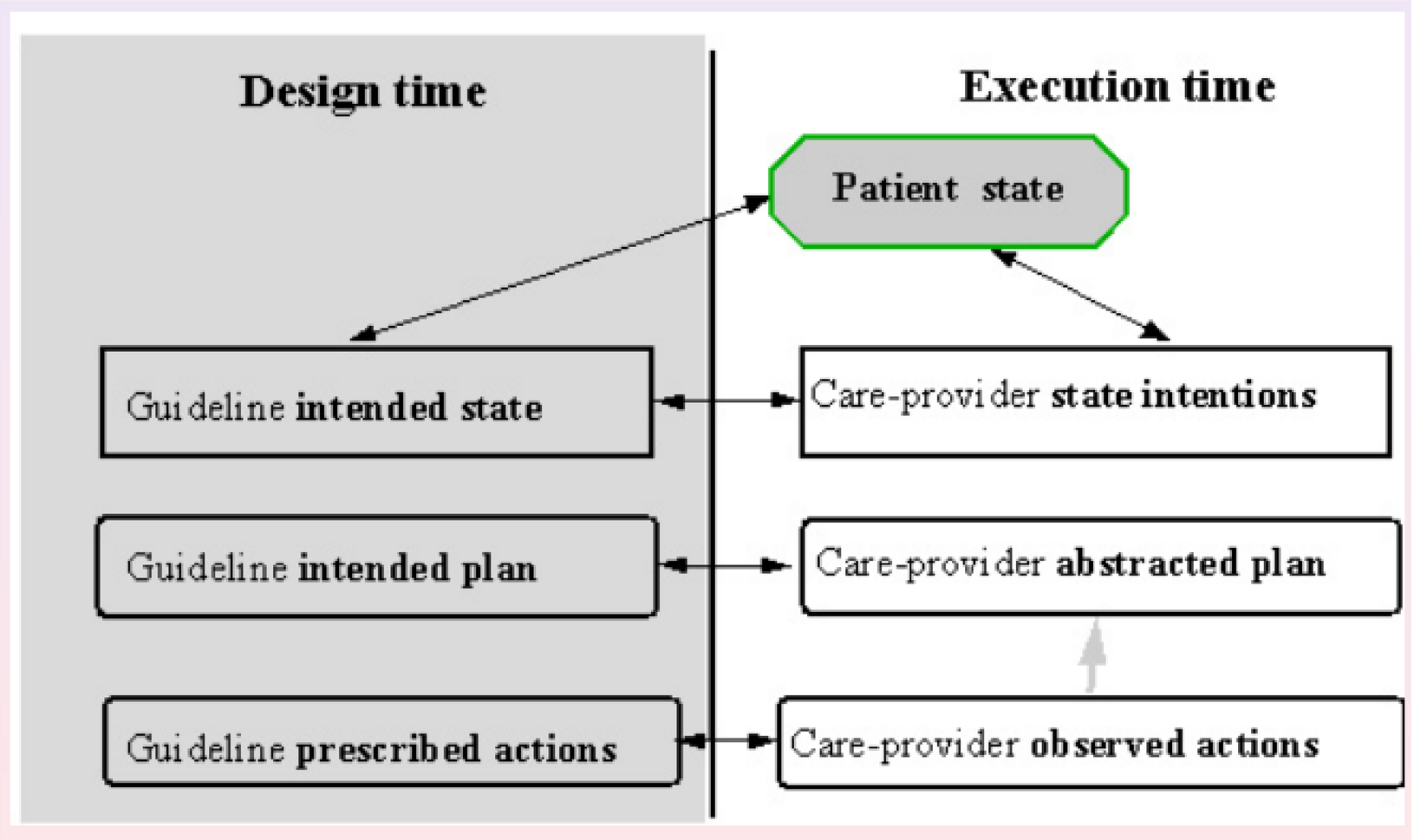
The design-time versus execution-time



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Asbru: a global ontology for guideline-application tasks

Asbru is a language specific to the set of guideline-support tasks and the problem-solving methods performing these tasks.

Enables a designer to represent a clinical guideline, including all of the knowledge roles useful to one or more of the problem-solving methods performing the various tasks supporting the application of clinical guidelines.

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Features of Asbru

- prescribed actions can be continuous;
- plans might be executed in parallel, in sequence, in a particular order, or every time measure;
- temporal scopes and parameters of guideline plans can be flexible;
- explicit intentions and preferences can underlie the plan

These features are in contrast to most traditional plan-execution representations, which have significant limitations and are not applicable to dynamic environments such as clinical domains.

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Features of Medical Domains

- actions and effects are not necessarily instantaneous;
- goals often have temporal extensions;
- there is uncertainty regarding the effect of available actions;
- unobservable, underlying processes determine the observable state of the world; a goal may not be achievable;
- parallel and periodic execution of plans is common.

The requirements of plan specifications in clinical domains are a superset of the requirements of typical toy domains used in planning research.

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Asbru Language

The **Asbru language** combines the flexibility and expressivity of procedural languages with the semantic clarity of declaratively expressed knowledge roles.

These roles are specific to the ontology of the methods performing the guideline-support tasks.

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The Asbru Time Annotation

- allows a representation of **uncertainty** in starting time, ending time, and duration of a time interval;
- supports **multiple time lines** by providing different reference annotations.

The **reference annotation** can be an absolute reference point, a reference point with uncertainty, a function of a previously executed plan instance, or a domain-dependent time point variable line

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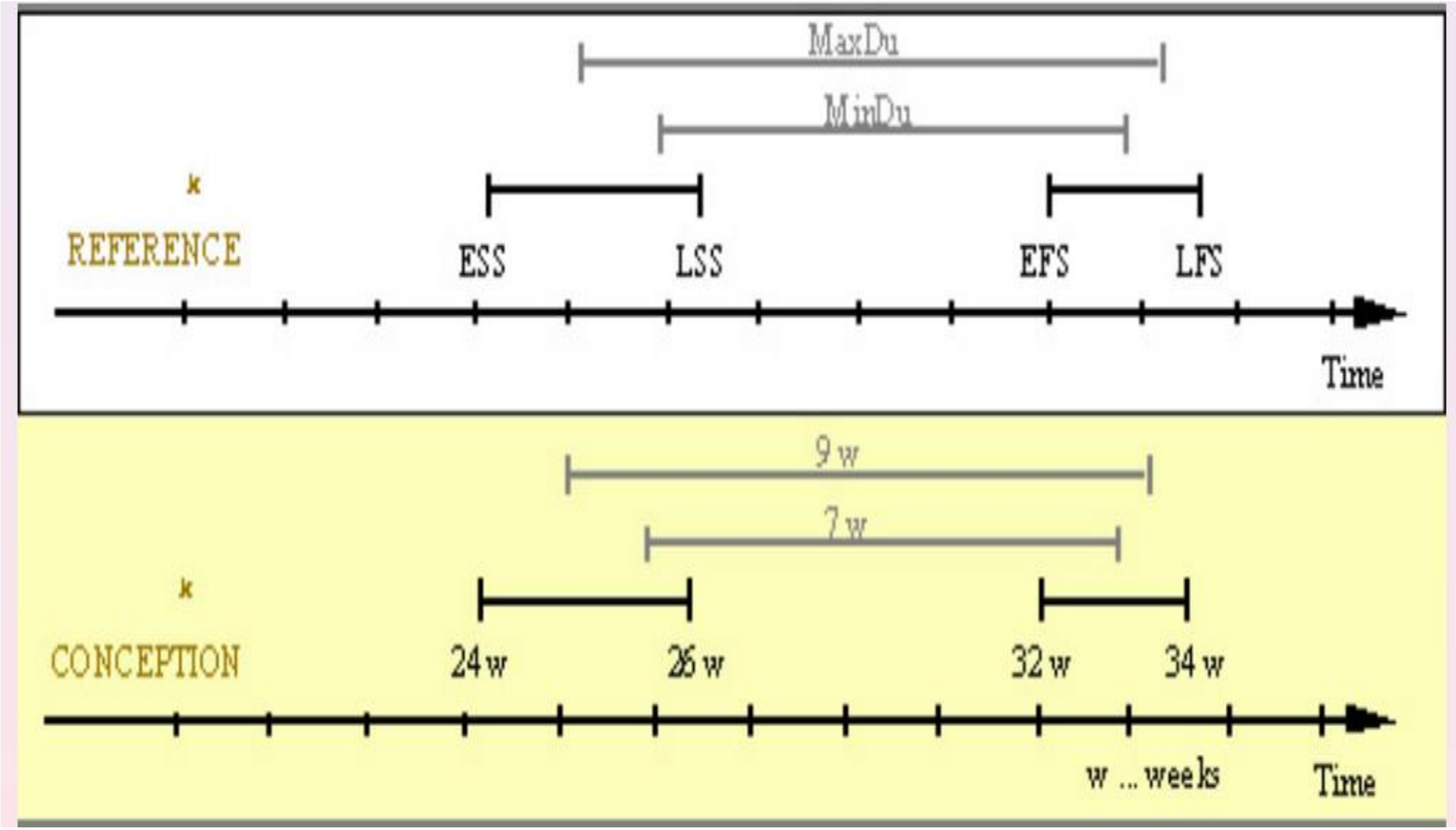
A schematic illustration of the Asbru time annotations



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The Asbru Time Annotation

The temporal annotation represents for each interval:

- the earliest starting shift (ESS),
- the latest starting shift (LSS),
- the earliest finishing shift (EFS),
- the latest finishing shift (LFS),
- the minimal duration (MinDu),
- the maximal duration (Maidus).

Temporal shifts are measured in time units. Thus, a temporal annotation is written as

([ESS, LSS], [EFS, LFS], [MinDu, MaxDu], REFERENCE)

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The Asbru Time Annotation

To allow temporal repetitions, the Asbru designers have defined the notion of:

- **cyclical time points** (e.g., MIDNIGHTS, which represents the set of midnights, where each midnight occurs exactly at 0:00 a.m., every 24 hours);

- **cyclical time annotations** (e.g., MORNINGS, which represents a set of mornings, where each morning starts at the earliest at 8:00 a.m., ends at the latest at 11:00 a.m., and lasts at least 30 minutes).

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The semantics of the Asbru task-specific knowledge roles

- A guideline is composed of a set of plans with arguments and time annotations.
- A decomposition of a plan into its sub plans is always attempted by the runtime application module, unless the plan is not found in the guideline library: thus representing a non-decomposable plan.
- A **non-decomposable plan** is executed by the clinical user or by an external call to a computer program.
- These runtime semantics can be viewed as a “semantic” halting condition, which increases runtime flexibility.
- The library includes a set of primitive plans to perform interaction with the user or to retrieve information from the medical patient record (e.g., OBSERVE, GET-PARAMETER, ASK-PARAMETER, DISPLAY, WAIT).
- All plans have return values.
- Generic library plans have states (**considered**, **possible**, **rejected**, and **ready**), that determine whether the plan is applicable and whether a plan instance can be created.
- At execution time, a **ready plan** is instantiated.

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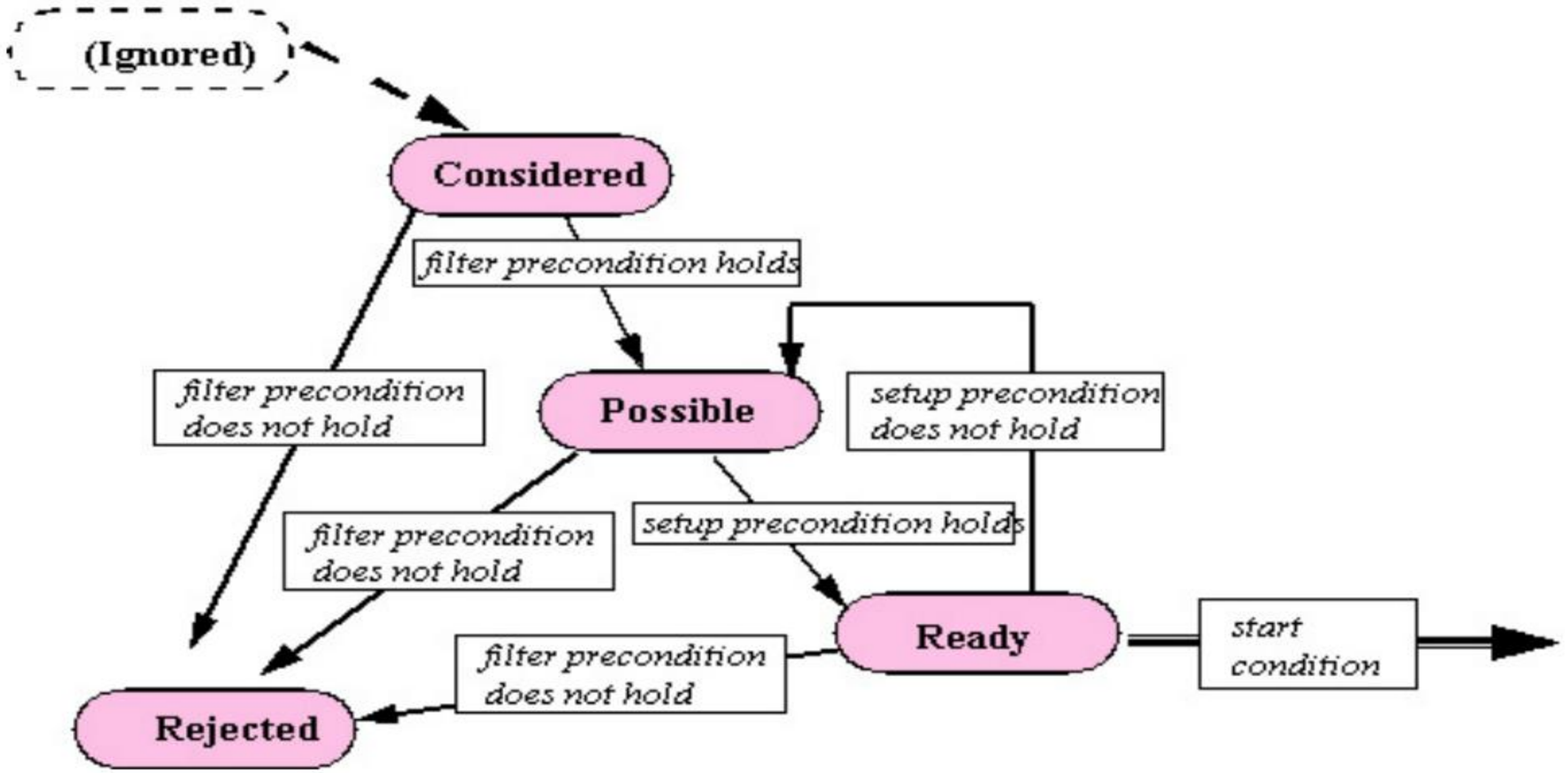
Plan-selection states and their state-transition conditions in Asbru



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The semantics of the Asbru task-specific knowledge roles

- A set of mutually exclusive plan states describes the actual status of the plan instance during execution.

- Particular **state-transition criteria** specify transition between neighboring plan-instance states.
  - if a plan is **activated**, it can only be **completed**, **suspended**, or **aborted** depending on the corresponding criteria;
  - the **suspended** state is optional and available for complex plans.

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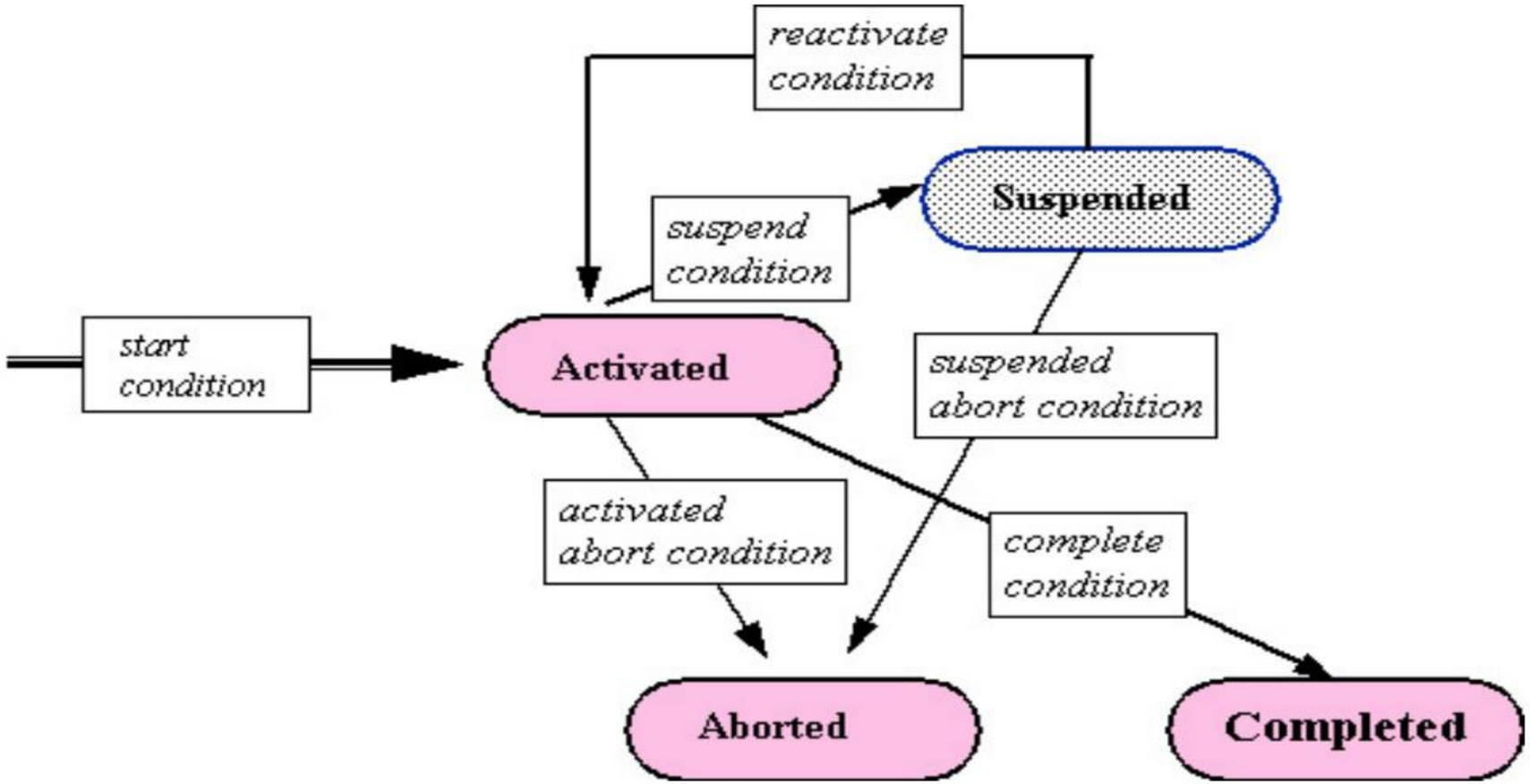
Plan-execution states and their state-transition conditions in Asbru



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The semantics of different state-transition conditions

A plan consists of a name, a set of arguments, including a time annotation, and five (optional) components:

- preferences
- intentions
- conditions
- effects
- plan body

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Preferences

1. **Strategy:** a general strategy for dealing with the problem (e.g., aggressive, normal);
2. **Utility:** a set of utility measures (e.g., minimize the cost or the patient inconvenience);
3. **Select-method:** a matching heuristic for the applicability of the whole plan (e.g., exact-fit);
4. **Resources:** a specification of prohibited or obligatory resources (e.g., in certain cases of treatment of a pulmonary infection, surgery is prohibited and antibiotics must be used);
5. **Start-conditions:** an indication whether transition from a ready state of the generic plan to an activated state of the plan instance is automatic or requires approval of the user.

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Intentions

Intentions are high-level goals at various levels of the plan.

They are also temporal patterns of provider actions and patient states, at different levels of abstraction, which should be maintained, achieved, or avoided.

There are four categories of intentions:

1. **Intermediate state:** the patient state(s) that should be maintained, achieved, or avoided during the applicability of the plan (e.g., weight gain levels are slightly low to slightly high);
2. **Intermediate action:** the provider action(s) that should take place during the execution of the plan (e.g., monitor blood glucose once a day);
3. **Overall state pattern:** the overall pattern of patient states that should hold after finishing the plan (e.g., patient had less than one high glucose value per week);
4. **Overall action pattern:** the overall pattern of provider actions that should hold after finishing the plan (e.g., patient had visited dietitian regularly for at least three months).

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Conditions

Conditions are **temporal patterns, sampled at a specified frequency**, that need to hold at particular plan steps to induce a particular state transition of the plan instance.

A plan instance is completed when the complete conditions become true, otherwise the plan instance's execution suspends or aborts (often, due to failure).

Six types of conditions may be identified (next slide)

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Condition Types

1. **filter-preconditions:** which need to hold initially if a generic plan is applicable; these conditions are not goals to be achieved (e.g., patient is a pregnant female), and must be true to achieve a possible state;
2. **setup-preconditions:** which need to be achieved (usually, within a given time delay relative to the initial time of consideration of the plan) to enable a plan to start (e.g., patient had a glucose-tolerance test) and allow a transition from a possible plan to a ready plan
3. **suspend-conditions:** which determine when an active plan instance has to be suspended (e.g., blood glucose has been high for four days); these are informally the inverse of protection conditions in the planning literature, which have to hold during certain time periods;
4. **abort-conditions:** which determine when an active or suspended plan has to be aborted (e.g., there is an insulin-indicator condition: the patient cannot be controlled by diet);
5. **complete-conditions:** which determine when an active plan is completed, typically, but not necessarily, successfully (e.g., delivery has been performed);
6. **reactivate-conditions:** which determine when a suspended plan has to be reactivated (e.g., blood glucose level is back to normal or is only slightly high).

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Effects

Effects describe the functional relationship between either:

- each of the relevant plan arguments and measurable parameters it affects in certain contexts (e.g., the dose of insulin is inversely related in some fashion to the level of blood glucose);
- the overall plan and the clinical parameters it is expected to effect (e.g., the insulin-administration plan decreases the blood-glucose level).

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Plan-Body

The **plan body** is a set of plans to be executed in parallel, in sequence, in any order, or in some frequency.

The Asbru ontology distinguishes among three types of plans:

- **sequential plan:** specifies a set of plans that are executed in sequence; for continuation, all plans included have to be completed successfully.
- **concurrent plan:** can be executed either together, in parallel, or in any order. Asbru distinguishes two dimensions for classification of sequential or (potentially) concurrent plans: the number of plans that should be completed to enable continuation and the order of plan execution.
- **cyclical plan:** includes a plan that can be repeated, and optional temporal and continuation arguments that can specify its behavior. Start and end specify a starting and ending time point. Time base determines the time interval over which the plan is repeated and the start time, end time, and duration of the particular plan instance in each cycle.

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Asbru Example: A Gestational Mellitus Guideline

The guideline prescribes several concurrent monitoring and management plans following a glucose tolerance test (GTT) between 140 and 200 mg/dl.

The plan body consists of three plans that are executed in parallel (glucose monitoring, nutritional management, and monitoring for insulin indication), exist in the guideline-specification library, and are decomposable into other library plans.

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Asbru Example: A Gestational Mellitus Guideline

Semantic role	*Asbru Code (ASCII code version)*	*Explanation*
Time assign-ments	(DOMAIN-DEPENDENT TIME-ASSIGNMENT (SHIFTS DELIVERY <- 38 WEEKS) (POINT CONCEPTION <- (ask (ARG "what is the conception-date?"))) (ABSTRACTION-ASSIGNMENT (CYCLIC MIDNIGHTS <- [0, 0 HOURS, 24 HOURS] BREAKFAST-START-TIME <- [0, 7 HOURS, 24 HOURS]))	Time-annotations serve to es-tablish domain-specific temporal terms. Delivery is a point occur-ring 38 weeks after Conception, whose date is acquired from the user. Midnights and breakfast start times are periodic shifts ev-ery 24 hours from the 12:00A.M. time.
Plan body	(DO-ALL-TOGETHER (glucose-monitoring) (nutrition-management) (observe-insulin-indicators)))	The plan body is a concurrent one; All three plans have to start together; all need to be completed to continue the next phase in the plan.

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Asbru Example: A Gestational Mellitus Guideline (cont.)

Semantic role	*Asbru Code (ASCII code version)*	*Explanation*
Conditions	(FILTER-PRECONDITIONS (one-hour-GTT-results (140, 200) pregnancy [-, -], [-, -], [-, -], CONCEPTION]) (SETUP-PRECONDITIONS (PLAN-STATE one-hour-GTT COMPLETED [[24 WEEKS, 24 WEEKS], [26 WEEKS, 26 WEEKS], [-, -], CONCEPTION]) (COMPLETE-CONDITIONS (delivery TRUE GDM-Type-II * (SAMPLING-FREQUENCY 24 HOURS))) (SUSPEND-CONDITIONS (STATE(blood-glucose) HIGH GDM-Type-II [[24 WEEKS, 24 WEEKS], [DELIVERY, DELIVERY], [4 DAYS, _], CONCEPTION](SAMPLING-FREQUENCY 24 HOURS))) (REACTIVATE-CONDITIONS (STATE(blood-glucose) (OR NORMAL SLIGHTLY-HIGH) GDM-Type-II [[24 WEEKS, 24 WEEKS], [DELIVERY, DELIVERY], [-, -], CONCEPTION] (SAMPLING-FREQUENCY 24 HOURS))) (ABORT-CONDITIONS (insulin-indicator-conditions TRUE GDM-Type-II * (SAMPLING-FREQUENCY 24 HOURS)))	The entry conditions for considering the patient are that the results of a glucose-tolerance test (GTT) are within 140 and 200 gr/dl. To activate the guideline, the patient must have completed the GTT plan within 24 to 26 weeks of pregnancy.The guideline application is completed on delivery. Suspend the guideline if high blood-glucose levels, as defined in the GDM-Type-II context, exist for at least 4 days. Reactivate it if blood glucose levels are normal or slightly high. Abort the guideline if there a pattern of indication for insulin therapy is detected. For all conditions, sample the database every 24 hours to determine the guideline's status.

Asbru Example: A Gestational Mellitus Guideline (cont.)

Semantic role	*Asbru Code (ASCII code version)*	*Explanation*
Intentions	(INTENTION:INTERMEDIATE-STATE (MAINTAIN blood-glucose-post-meal (<= 130) GDM-Type-II [[24 WEEKS, 26 WEEKS], [DELIVERY, DELIVERY], [14 WEEKS, 16 WEEKS], CONCEPTION]) (MAINTAIN blood-glucose-fasting (<= 100) GDM-Type-II [[24 WEEKS, 26 WEEKS], [DELIVERY, DELIVERY], [14 WEEKS, 16 WEEKS], CONCEPTION])) (INTENTION:OVERALL-STATE (AVOID STATE(blood-glucose) HIGH GDM-Type-II [[24 WEEKS, 26 WEEKS], [DELIVERY, DELIVERY], [7 DAYS, _], CONCEPTION]))	During application of the guideline (starting around 24 to 26 weeks of conception, lasting until delivery, for a duration of 14 to 16 weeks), the target is to maintain postprandial blood glucose values at less than 130 gr/dl and fasting blood-glucose values at less than 100 gr/dl. An overall intention, to be assessed upon completion of the guideline, is that during the guideline's application, there was never a period of high blood-glucose level (in any context) lasting 7 day

Asbru Example: A Gestational Mellitus Guideline (cont.)

Semantic role	*Asbru Code (ASCII code version)*	*Explanation*
Preferences	(PREFERENCES (SELECT-METHOD EXACT-FIT) (START-CONDITION AUTOMATIC))	The match in the filter conditions needs to be exact to even consider the guideline for selection. Activation of the guideline by the automated interpreter can start without manual user approval
Effects	(EFFECTS ([GDM-Type-II Weight-at-birth Normal [DELIVERY, DELIVERY], [DELIVERY, DELIVERY], [_, _], CONCEPTION]), 80%)	Expected effects of the guideline include a normal (for this context) weight at birth; estimated likelihood of achievement of the effect is 80%.

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Guideline Intentions

The design-time and run-time model underlying Asgaard implies a specific guideline-application critiquing framework.

In this framework, five comparison axes exist:

- the guideline's prescribed actions versus the provider's actual actions;
- the guideline's intended plan versus the provider's plan;
- the guideline's intended patient state versus the provider's state intention;
- the guideline's intended state versus the patient's (abstracted) actual state;
- the provider's intended state versus the patient's (abstracted) actual state.

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Guideline Intentions

Combinations of the comparison results imply a set of different **behaviors** of the guideline application by the provider.

In theory, there might be up to 32 different behaviors, or assessment vectors, assuming binary comparisons along five axes.

However, the use of consistency constraints prunes this number to approximately **10 major behaviors**.

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Several of the typical application behaviors

Intended action vs. physician action	*Intended plan vs. physician plan*	*Intended state vs. physician intention*	*Intended state vs. patient state*	*physician intention vs. patient state*	*Description of the behavior*
+	+	+	+	+	physician executes protocol as specified; protocol succeeds
+	+	+	-	-	physician follows guideline, has the same intentions, but guideline does not work
-	+	+	+	+	overall plan intention followed, albeit through different actions, and it works
-	-	+	+	+	physician follows neither actions nor overall plan; state intentions agree and both succeed
-	-	+	+	+	physician follows neither action nor plan; state intentions differ, and neither materializes

Guideline Intentions

Access to the original process and outcome intentions of the guideline designers supports forming an automated critique of **where**, **when**, **how much** the care provider seems to be deviating from the suggested process of applying the guideline, and in **what way** and to **what extent** the care provider's outcome intentions might still be similar to those of the author's.

Note also that intentions are much more specific than general themes such as reducing mortality and morbidity; these cannot be monitored effectively during the lifetime of the guideline's application.

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Monitoring and therapy of patients who have insulin-dependent diabetes

- The diabetes-guideline's prescribed action might be to increase the dose of the insulin the patient typically injects before dinner.

- The provider recommends reduction of the patient's carbohydrate intake during dinner.
  - This action seems to contradict the prescribed action.

The automated assistant notes that the state intention of the guideline was "avoid more than two episodes of hyperglycemia per week".

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Monitoring and therapy of patients who have insulin-dependent diabetes

By recognizing this high-level intention and its achievement by a different plan, the automated assistant can accept the provider's alternate set of actions, and even provide further support for these actions.

A plan-recognition ability is an indispensable prerequisite to the performance of plan critiquing.

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An automated graphical knowledge-acquisition (KA) tool

- A significant benefit of the KA tool approach is that it detects incorrect syntax while authoring a guideline.
- The complexity of the ontology enforced the automatic generator of the KA tool to produce a user interface with many cascading, small dialogs.
- An important enhancement was the addition of a specialized string editor that accepted as input the BNF syntax of Asbru temporal annotations, and creates automatically a graphical KA tool that acquires legal strings from the user

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The AsbruView system

A significant improvement in the process of acquisition and maintenance of Asbru guidelines was the development, by the Vienna team of the Asgaard project, of the **AsbruView visual module** for specification and browsing of Asbru guidelines.

The AsbruView system enriches the timeline graphic representation by adopting a 3D visualization:

- two usual dimensions on which the different (possibly overlapping) parts of plans are temporally laid out;
- a third dimension is used to add graphic elements which convey further information (e.g., when a plan is completed, or might be suspended, or aborted, . . .).

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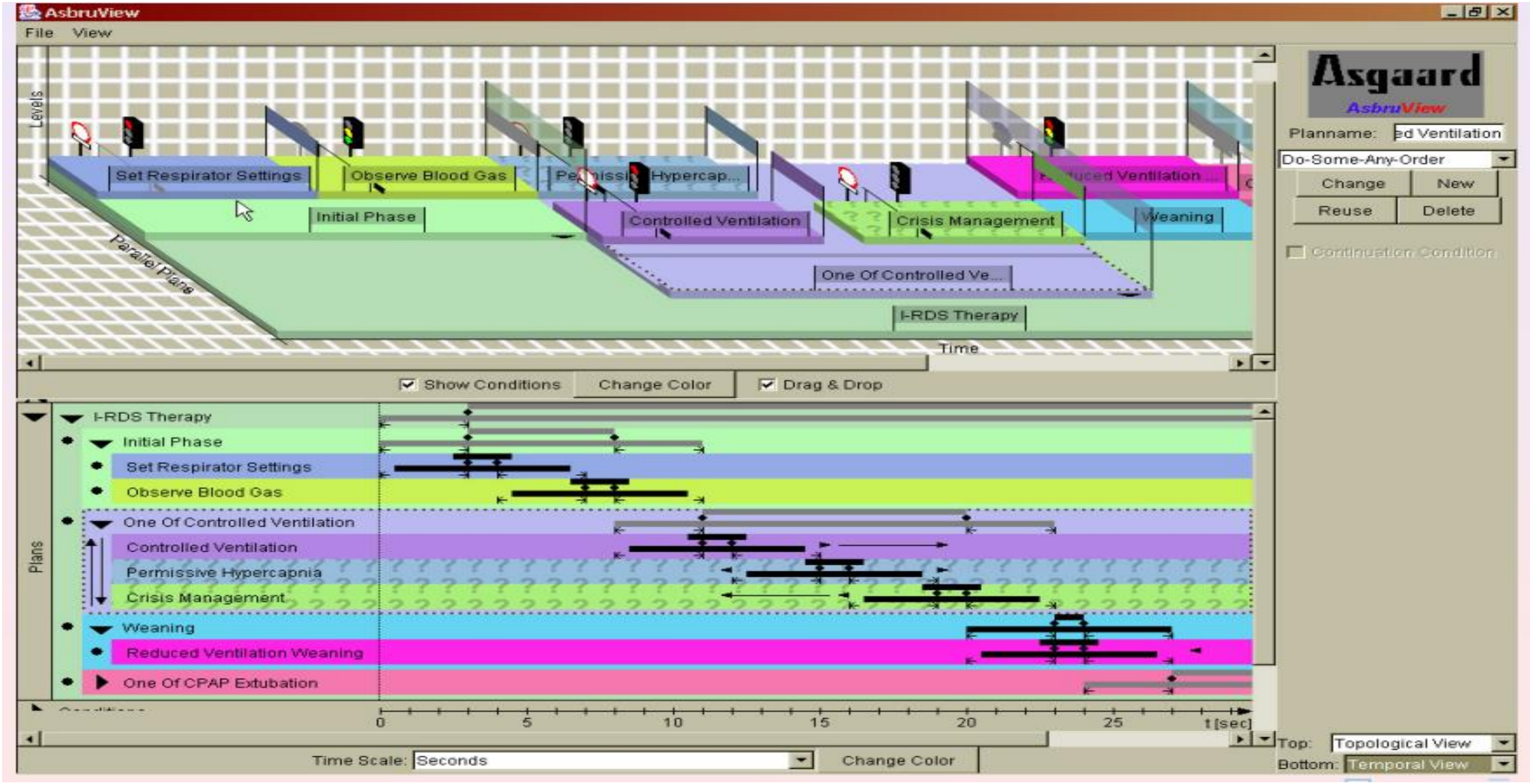
The AsbruView system



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Hybrid Guideline Representations and the DeGeL Project

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The Guideline Conversion Problem

“How will the large mass of free-text guidelines be converted to a formal machine-readable language?”

- expert physicians cannot program in guideline-specification languages;
- programmers and knowledge engineers do not understand the clinical semantics of the guidelines.

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The Guideline Conversion Problem

Some of the guideline's knowledge is of implicit nature, clear only to the expert physician authoring the guideline.

This knowledge must become explicit during the conversion process.

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Features of the Conversion Process

- must support and facilitate collaboration amongst these two very different types of users;
- machine-executable representations are crucial for providing computerized assistance;
- for some other tasks, such as search and retrieval of relevant guidelines, text-based representations are of a significant importance;
- the conversion process must support embedding in the guideline's representation terms from **standardized medical vocabularies**.

All these considerations have led to the development of the **Digital electronic Guideline Library (DeGeL) architecture**.

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The Hybrid Guideline-Representation Model

To gradually convert clinical guidelines to machine-comprehensible representations, Shahar and his colleagues have developed:

- a hybrid, multifaceted representation;
- an accompanying distributed architecture;
- a set of Web-based software tools.

The specification tools incrementally and in iterative fashion transform a set of clinical guidelines through several intermediate phases, into a fully formal, machine comprehensible representation of guidelines.

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The Gradual Conversion Process

The conversion process is performed gradually using the following current representation formats:

1. **Semi-structured text:** snippets of text assigned to top-level target-ontology knowledge-roles (Asbru filter conditions and outcome intentions);
2. **Semi-formal representation:** further specification of the structured text, adding more explicit procedural control structures, performed jointly by the knowledge engineer and expert physician, such as specification in explicit fashion of Asbru sequential and concurrent actions;
3. **Formal representation:** final specification performed by the knowledge engineer, resulting with the guideline converted a machine-comprehensible format, such as an Asbru plan executable by an Asbru runtime execution module.

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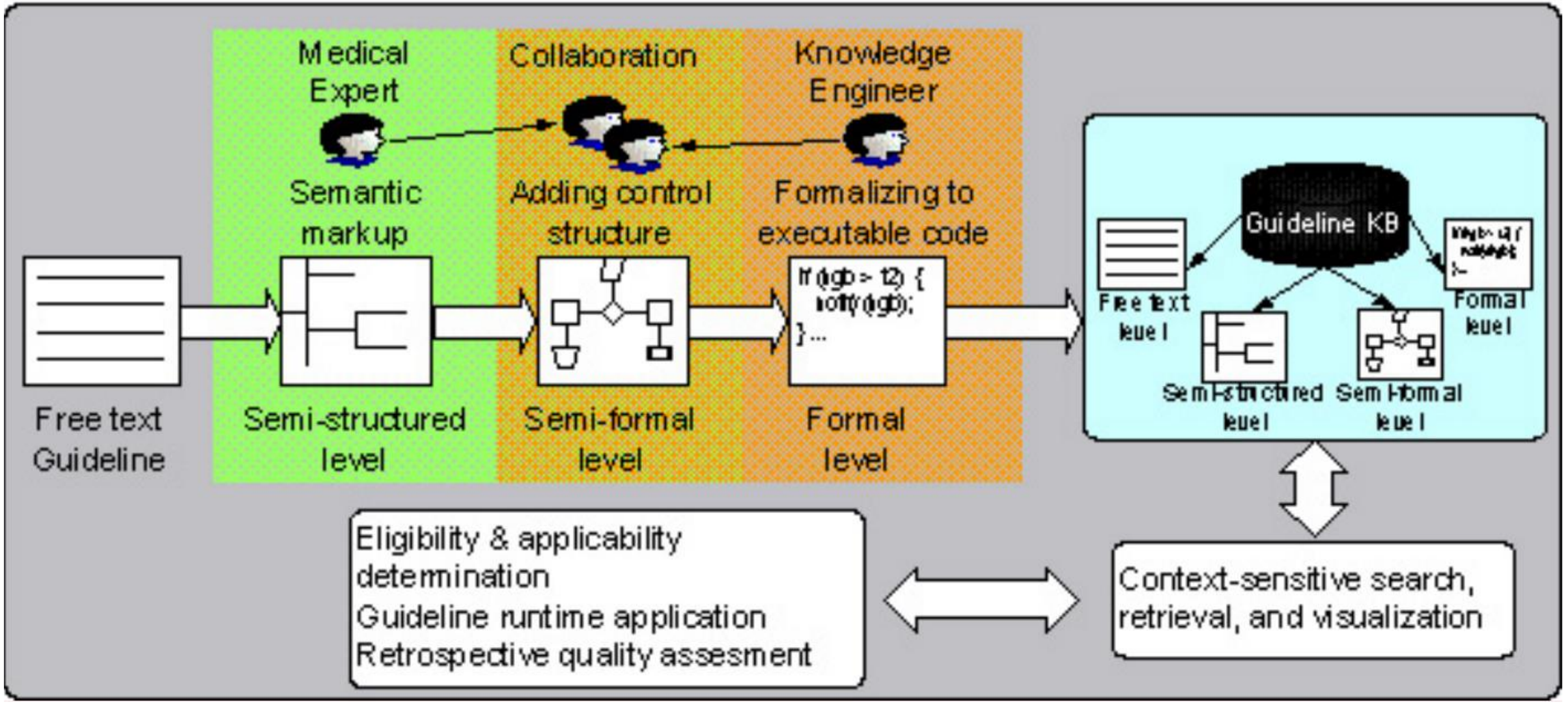
The incremental conversion process in the DeGeL architecture



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The DeGeL architecture

The **DeGeL architecture** was designed to handle all of the hybrid guideline-representation levels.

The DeGeL framework's guideline knowledge-base and various task-specific tools were designed to support all of the design time and runtime tasks involved in guideline-based care.

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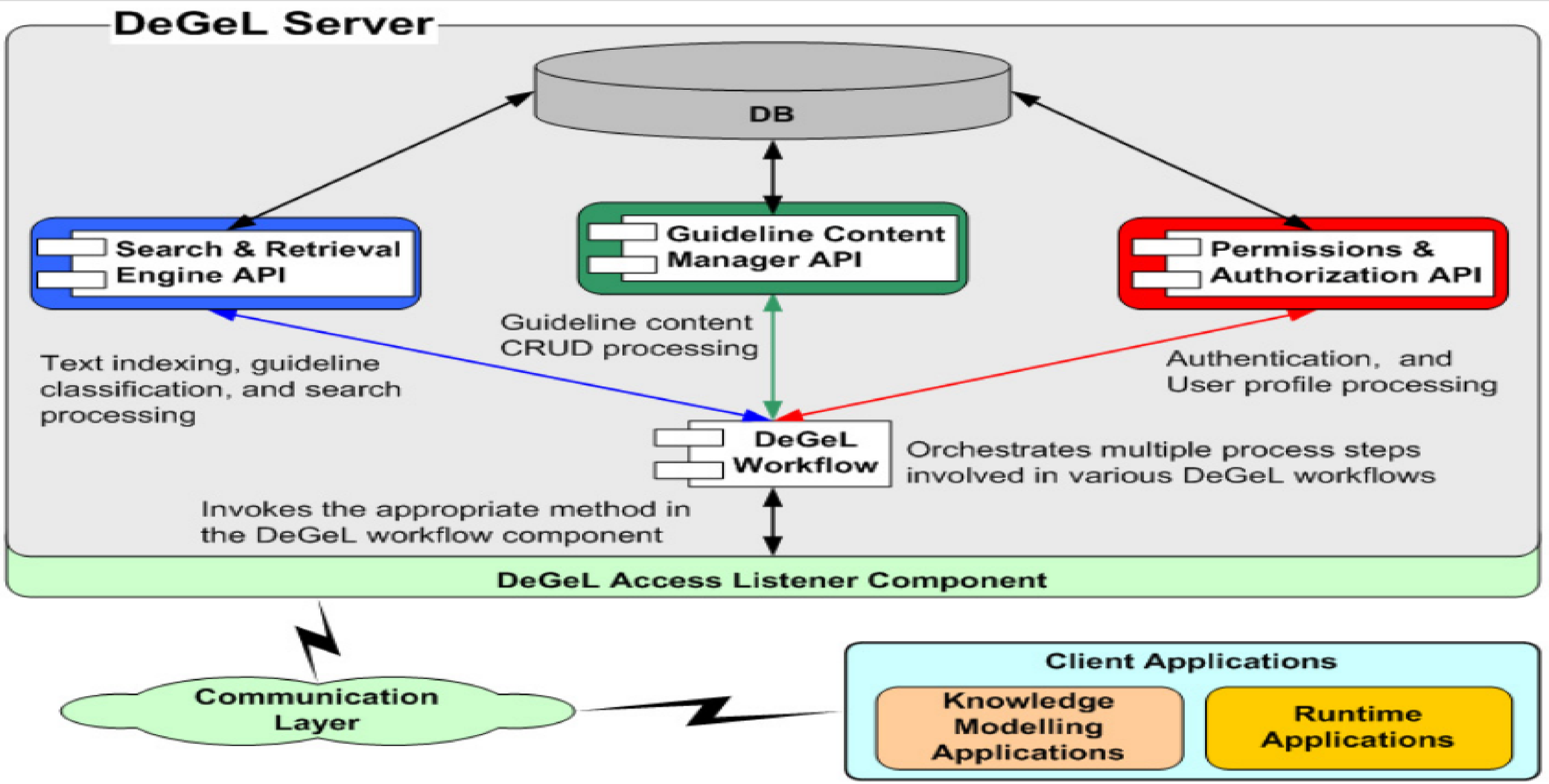
The conceptual architecture of a typical DeGeL server



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The DeGeL Hybrid Meta-Ontology

To support the specification of a guideline in one or more different guideline specification languages, the DeGeL architecture includes a **hybrid guideline meta-ontology.**

The meta-ontology is composed of two components:

1. A **documentation meta-ontology**, which specifies knowledge roles common to all target guideline ontologies, and defines the ontologies of the sources of the guidelines and of the marked-up guidelines;
2. A **specification meta-ontology** for describing a new target ontology, in order to enable adding it into the DeGeL (meta) knowledge base. An XML schema describes how to generate XML documents that conform to the DeGeL expected structure.

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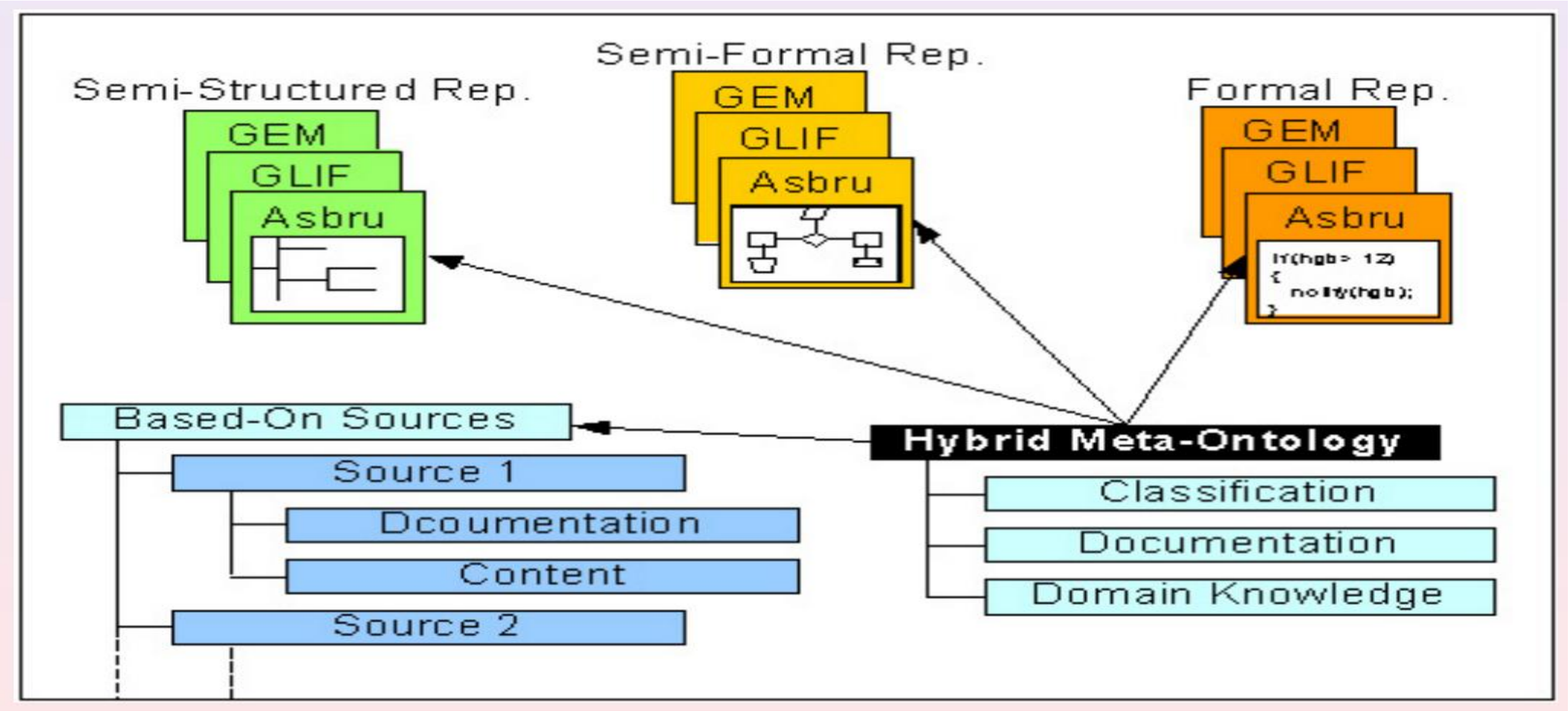
DeGeL's Hybrid Meta-Ontology



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DeGeL's Hybrid Meta-Ontology

The documentary component of the hybrid-meta ontology includes several knowledge-roles, such as **documentation**, common to all guideline ontologies.

It distinguishes:

- **source guidelines**, which are free-text guidelines uploaded to DeGeL;
- **hybrid guidelines**, which are the output of the gradual hybrid conversion process.

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Source Guideline

- Uploading a guideline into the DeGeL library (e.g., a document published by a professional society) creates a source guideline.
- A guideline source can be named, searched, and retrieved, and is annotated using the dedicated source-guideline ontology, which documents the source-guideline's details
- However, a source guideline cannot be indexed or applied to a patient.

Hybrid Guideline

- A hybrid guideline is a more complex structure; it can be indexed, retrieved, modified, and applied
- It includes one or more source guidelines;
- It includes the semi-structured, semi-formal, and fully-structured (machine-comprehensible) representations of the guideline using the selected target ontology.

- ❑ Several DeGeL tools are used mostly to specify and retrieve guidelines, irrespective of a particular patient.
- ❑ Other tools are used mostly at runtime and require automated or manual access to patient data.
- ❑ All of the tools were designed to support the various formats implied by a hybrid representation.

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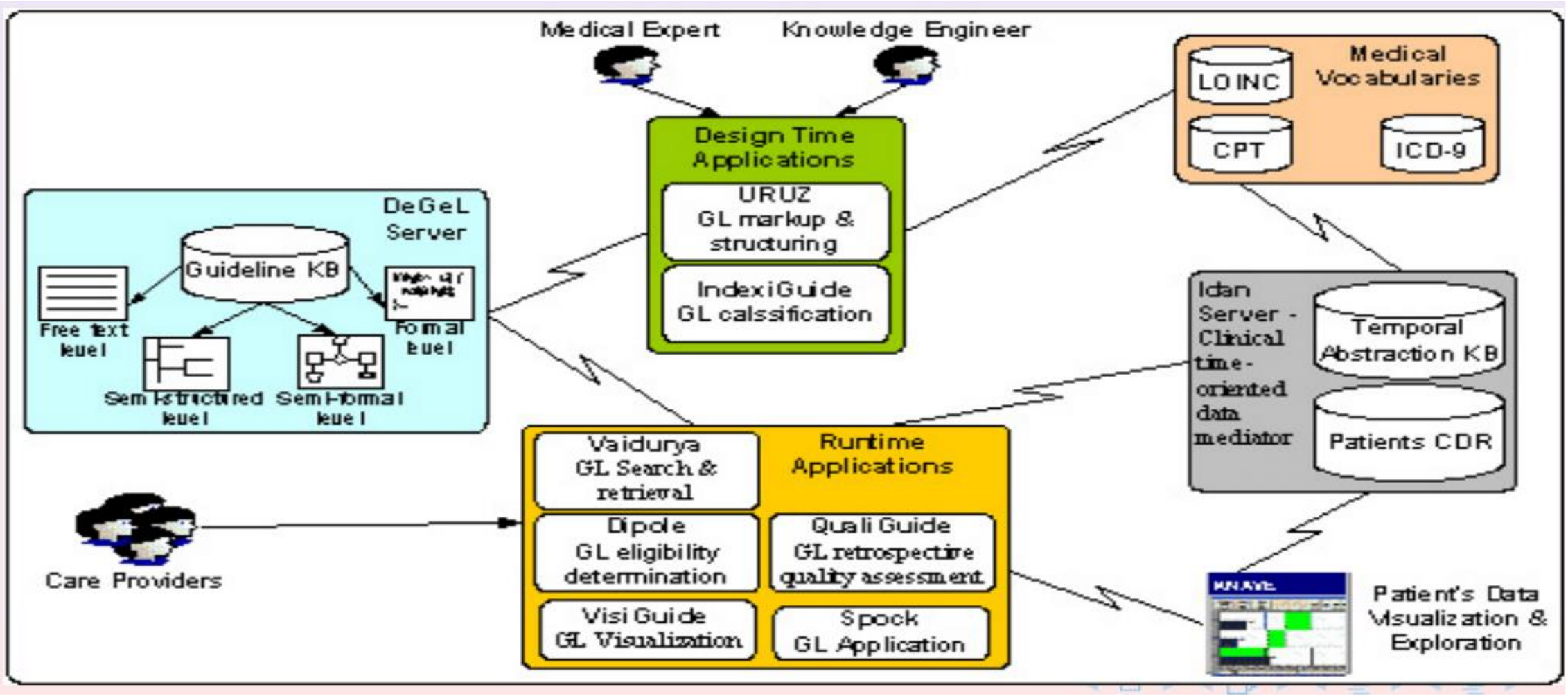
The overall DeGeL guideline-support architecture



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The DeGeL architecture components

Uruz: Semantic markup

This tool enables medical experts to create new guideline documents

IndexiGuide: Semantic classification of guidelines

This tool enables the medical expert to index the guideline document, in order to facilitate its subsequent retrieval

Vaidurya: Concept-based and context-sensitive search and retrieval of guidelines

This hybrid guideline search and retrieval tool exploits the existence of the free-text source, the semantic indices, and the marked semi-structured-text.

VisiGuide: Semantic browsing of clinical guidelines

This browsing and visualization tool enables users to browse a set of guidelines returned by the Vaidurya search engine and visualize their structure

DeGeLock: Authorization and permission of the DeGeL Library

Due to practical and legal considerations, any digital guideline library must include a comprehensive authorization model

The DeGeL runtime tools:

runtime guideline application and retrospective quality assurance of guideline-based care

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Clinical Guidelines – concluding remarks

Clinical guidelines are here to stay for a long time, and their efficacy, when followed, is established.

- Frameworks for complex, multi-step, longitudinal care plans, which can handle incremental execution over long time periods, are needed.
- There is still a clear need for effective integration of automated guideline-support tools at the point of care and at the point of quality assessment.
- To be effective, these tools will need to be linked to the patient's local record using standardized communication protocols, medical-record schemas, and controlled medical terminologies.

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Summary

- ❑ An introduction to clinical guidelines
- ❑ Automation of clinical guidelines
- ❑ Automation of complex, longitudinal, guideline-based care
- ❑ The Asgaard project and the Asbru language
- ❑ Hybrid guideline representations and the DeGeL project

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