Automated Collaboration on the Semantic Web

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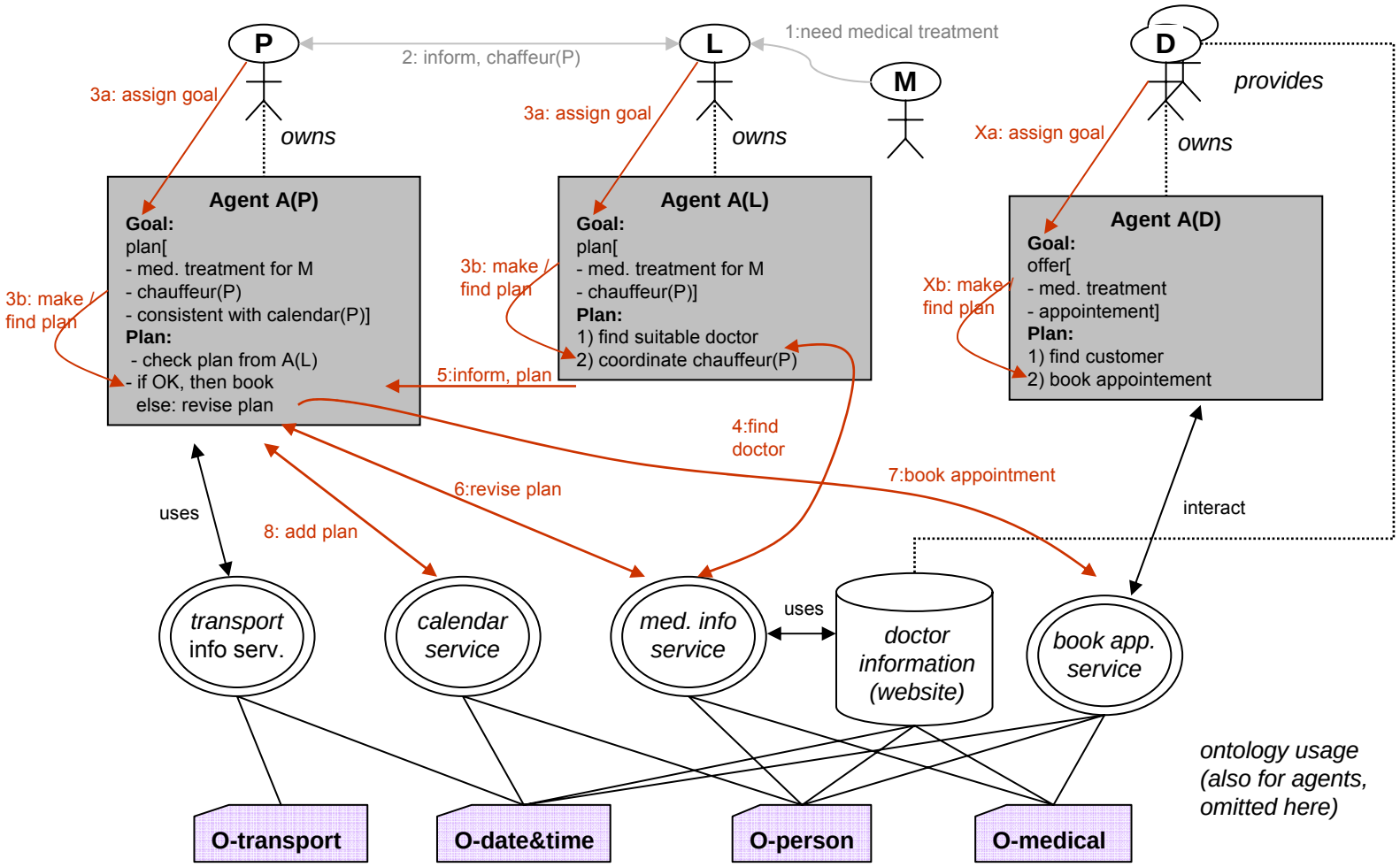
Motivating Example

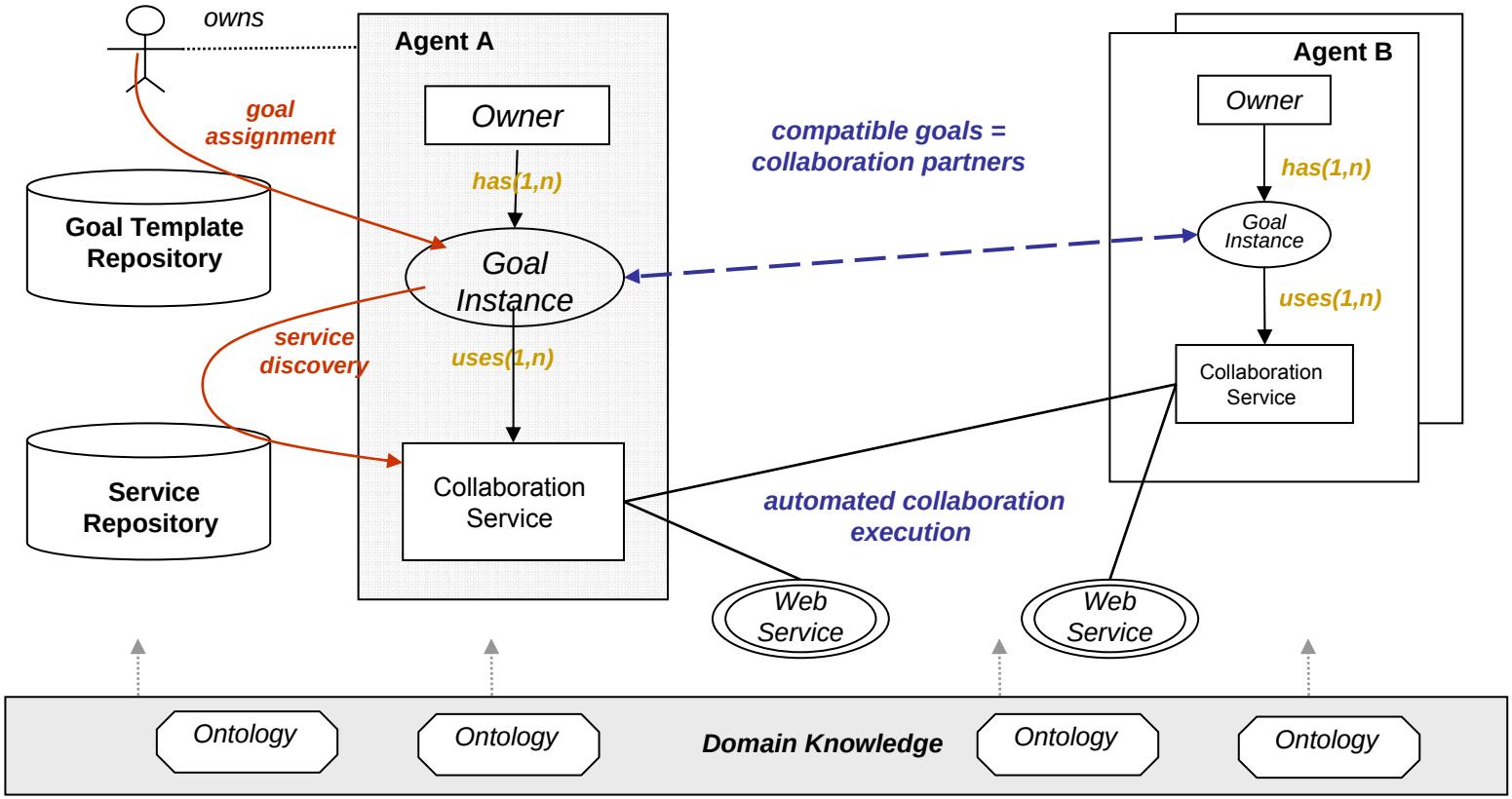


Aim, Approach, and Scope

- Framework & Prototype for Automated Collaboration on the Semantic Web
  - Model of Agency
  - Semantic Element Description
  - Semantically driven Collaboration Establishment
  - Prototype

- Extension of the Web Service Modeling Ontology WSMO
  - comprehensive framework for Semantic Web Services
  - core elements: Ontologies, Goals, Web Services, Mediators
  - serves as basis for element descriptions
  - compatibility / usability of WSMO technologies for SW(S)

Conceptual Architecture



Ontologies as Data Model

- **Ontologies are used as the 'data model'**
  - all element descriptions rely on ontologies
  - all data interchanged in collaborations usage are ontologies
  - semantic information processing & ontology reasoning
- **Ontology Language WSML (Web Service Modeling Language)**
  - conceptual syntax for describing WSMO elements
  - well-layered logical language for axiomatic expressions (WSML Layering)
  - Ontology design: modularization & decoupling
- **Ontology Technology needed:**
  - ontology management (editing, maintenance)
  - ontology instance data handling
  - ontology integration techniques (mapping, merging, alignment)

Ontology Specification

- **Non functional properties** item description for management
- **Imported Ontologies** importing existing ontologies where no heterogeneities arise
- **Used mediators** OO Mediators (ontology import with terminology mismatch handling)

Ontology Elements:

Concepts	set of concepts that belong to the ontology, incl.
Attributes	set of attributes that belong to a concept
Relations	define interrelations between several concepts
Functions	special type of relation (unary range = return value)
Instances	set of instances that belong to the represented ontology
Axioms	axiomatic expressions in ontology (logical statement)

Model of Agency

electronic representative of a real world entity
that wants to achieve individual objectives
by collaborative interactions with others

- **Requirements**
  - represent owner (optional: agent collaboration)
  - Goals for specifying collaboration objectives (via task delegation by owners)
  - dynamic usage of Collaboration Services as facilities for participating in automated collaborative interactions over the (Semantic) Web
  - semantic description (all data based on ontologies)
- **MoA extends "Collaborative Interface Agents"**
  - general agents properties: autonomous, social, re-& proactive
  - re- & productivity by interaction with user and other agents
  - extensions: semantic description, Collaboration Services, Coll. Management

Agent Semantic Description

Agents

electronic representative of real world entity that wants to achieve an objective by automated collaboration

Class agent
- hasNonFunctionalProperties **type** nonFunctionalProperties
- importsOntology **type** ontology
- usesMediator **type** ooMediator
- owner **type** owner
- collaboration **type** collaboration
- history **type** collaboration

Class owner
- hasNonFunctionalProperties **type** nonFunctionalProperties
- owner **type** instance
- preference **type** axiom
- policy **type** axiom
- serviceUsagePermission **type** service

Class collaboration
- hasNonFunctionalProperties **type** nonFunctionalProperties
- goal **type** goal *single-valued*
- service **type** service

SWF

Goals

Objective to be achieved that a user (agent owner) delegates to an agent for automated resolution

- **Definition and Usage**
  - denotes state of the world that is to be achieved (formal / machine-readable specification)
  - serves as facility for automated usage of Collaboration Service
  - semantic formal / machine-readable specification for automated processing (desired state defined by logical expressions on domain ontologies)

- **Goal Driven Architecture**
  - objective definition independent of available facilities (decoupling "desires" and "requests")
  - automated goal resolution (dynamic discovery of partners and resources for resolution)
  - allows dynamic use & re-use of Services for different purposes
  - derived from different AI-approaches for intelligent systems (agent BDI architectures, PSMs, Planning / Service Composition)

- **Goal Templates and Goal Instances**
  - Goal Templates as "pre-defined schemas of Goals resolvable in system / application"
  - user defines Goal Instance for concrete objectives by instantiating a Goal Template and assigning it to an agent for automated resolution

Goals Semantic Description

Goal Template

predefined schema of user objective, described as WSMO 1.0 goal

Class goalTemplate **is-a** wsmov1.0Goal

hasNonFunctionalProperties **type** nonFunctionalProperties
importsOntology **type** ontology
usesMediator **type** {ooMediator, ggMediator}
hasPostcondition **type** axiom
hasEffect **type** axiom

Goal Instance

concrete objective assigned to an agent, instantiated Goal Template, client for service usage

Class goalInstance **sub-Instance** goalTemplate

hasNonFunctionalProperties **type** nonFunctionalProperties
importsOntology **type** ontology
usesMediator **type** ooMediator
hasPostcondition **type** axiom
hasEffect **type** axiom
hasSubmission **type** instance
hasResult **type** instance
goalResolutionStatus **type** goalResolutionStatus

Collaboration Service Description

- complete item description
- quality aspects
- service management

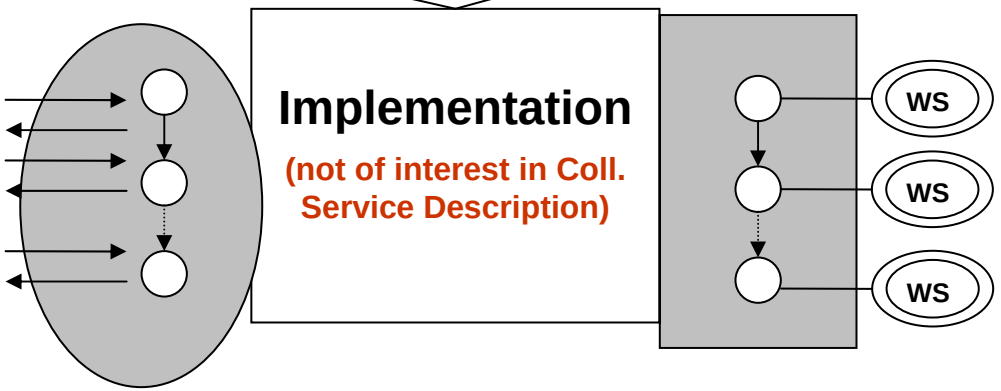
Non-functional Properties

DC + QoS + Version + financial

- service advertisement
- support for service discovery

Capability

functional description



interface for service consumption (agents = clients):
- external visible behavior
- communication structure
- 'grounding'

realization of functionality by:
- interaction with CS of other agents
- usage of other web rescoures / WS

Client Interface --- Service Interfaces --- **Orchestration**

(sub-class of WSMO Choreography) *(sub-class of WSMO Orchestration)*

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Collaboration Service Description

Collaboration Services

facility an agent uses for participating in an automatically executed collaboration
interacts with other agents and utilizes (Semantic) Web resources via its orchestration

Class collaborationService **is-a** wsmoService
- hasNonFunctionalProperties **type** nonFunctionalProperties
- importsOntology **type** ontology
- usesMediator **type** ooMediator
- hasCapability **type** capability *single-valued*
  - hasSharedVariables **type** sharedVariable
  - hasPrecondition **type** axiom
  - hasAssumption **type** axiom
  - hasPostcondition **type** axiom
  - hasEffect **type** axiom
- hasInterface **type** interface
  - clientInterface **type** serviceInterfaceDescription
  - orchestration **type** serviceInterfaceDescription

Class serviceInterfaceDescription **sub-Class** wsmoServiceInterface
- hasNonFunctionalProperties **type** nonFunctionalProperties
- importsOntology **type** ontology
- usesMediator **type** ooMediator
- hasVocabulary **type** concept_in, concept_out, concept_controlled
- hasState **type** ontology
- hasGuardedTransition **type** if (condition) then *update* – for client interface
  if (condition) then *operation(CS, R, update)* – for orchestration

Capability Specification

- **Non functional properties**
- **Imported Ontologies**
- **Used mediators**
  - *OO Mediator:* importing ontologies with mismatch resolution
  - *WG Mediator:* link to a Goal wherefore service is not usable a priori
- **Pre-conditions**
  what a web service expects in order to be able to provide its service (conditions over the input)
- **Assumptions**
  conditions on the state of the world that has to hold before the Web Service can be executed
- **Post-conditions**
  describes the result of the Web Service in relation to the input, and conditions on it
- **Effects**
  conditions on the state of the world that hold after execution of the Web Service (i.e. changes in the state of the world)

Service Interface Description Model (adopted from WSMO)

- common formal model for Service Interface description
  - ontologies as data model
  - based on ASMs
  - not restricted to any executable communication technology
- general structure:
  - Vocabulary Ω:
    - ontology schema(s) used in service interface description
    - usage for information interchange: in, out, shared, controlled
  - States ω(Ω):
    - a stable status in the information space
    - defined by attribute values of ontology instances
  - Guarded Transition GT(ω):
    - state transition
    - general structure: ***if*** (condition) ***then*** (action)
    - different for Choreography and Orchestration
    - additional constructs: *add, delete, update*

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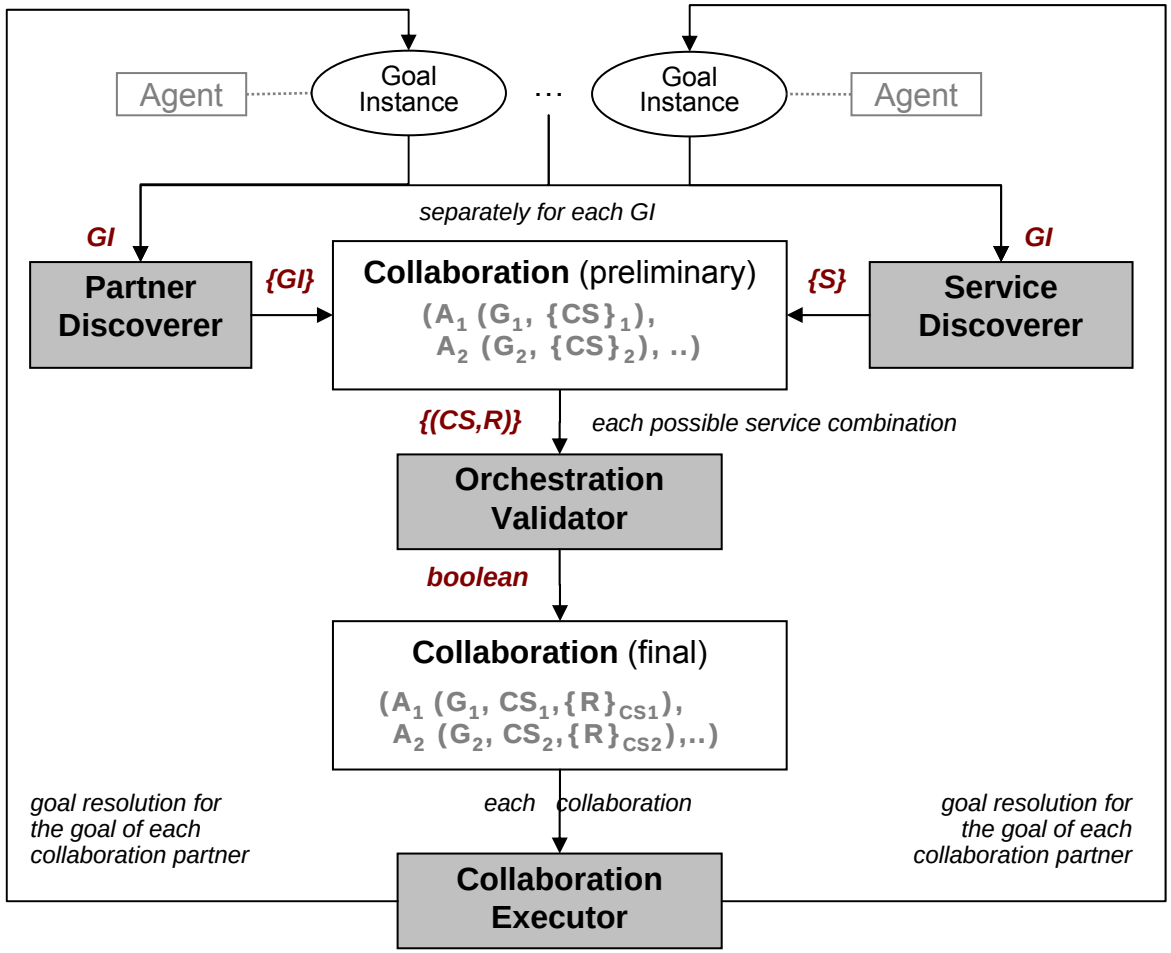
Collaboration Management



Semantically Driven Discovery

find appropriate (Web) facility for automatically resolving a goal as the objective of a requester

Key Word Matching
match natural language key words in resource descriptions

Controlled Vocabulary
ontology-based key word matching

Semantic Matchmaking
... what Semantic Web Services aim at

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Action and Object Knowledge

- Knowledge Types Distinction
  - Action = activity to be performed on object (e.g. buy, sell, ..)
  - Object = entity that action is performed on (e.g. product, ticket, ...)
- Action and Object Knowledge is different
  - "Action" defines what is to be done; interacting entities need to have **compatible actions** (e.g. buy <-> sell)

  => Action-Resource Ontology
  - "Object" defines whereon an action is to be performed; interacting entities need to have **not-contradicting object definitions**

  => Set-theoretic Object Matchmaking

- **Combination is needed** (agents / resources might have not-contradicting objects but incompatible actions)

Action-Resource Ontology

```
concept action
  compatibleAction symmetric ofType action
concept buy subConceptOf action
  compatibleAction symmetric ofType sell
concept sell subConceptOf action
  compatibleAction symmetric ofType buy
```

Action Taxonomy

```
concept resource
  hasAction ofType set action
concept goal subConceptOf resource
concept service subConceptOf resource

concept buyergoal subConceptOf goal
   hasAction ofType set buy
concept sellerservice subConceptOf service
   hasAction ofType set sell
```

Resource Taxonomy

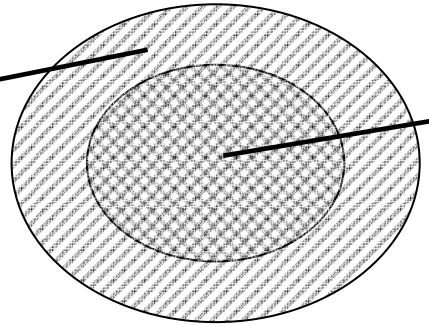
all resources are defined as instances of resource types

- **allows determining action compatibility / equality of agents & resources**
- **supports handling multi-party collaborations**

Object Matchmaking

Set-Based Resource Descriptions

Information Space
all possible instances
of used ontologies



Description Notion
all possible instances that
satisfy restricted information space

```
postcondition
  definedBy
    exists ?PurchaseItem(?PurchaseItem[
      item hasValue ?PurchaseFurniture
    ] memberOf swfmo:product) and
    exists ?PurchaseFurniture(?PurchaseFurniture[
      material hasValues {wood},
    ] memberOf furn:chair) and
  ?X[
     purchaseItem hasValue ?PurchaseItem,
     buyer hasValue kb:MichaelStollberg,
     purchasePayment hasValue kb:MSCreditCard
   ] memberOf swfmo:purchaseContract .
```

Goal Instance Postcondition

- Objective: receive a purchase contract for a wooden chair for Michael Stollberg, payment with credit card

- meta-varibale X (dynamically quantified by matchmaking notion)

- restrictions on several ontology notions

- WSML syntax

Set Theoretic Matchmaking Notions

1. Exact Match:

   $D_Q, D_R, O, M \models \forall x.\ (D_Q <=> D_R)$

2. PlugIn Match:

   $D_Q, D_R, O, M \models \forall x.\ (D_Q => D_R)$

3. Subsumption Match:

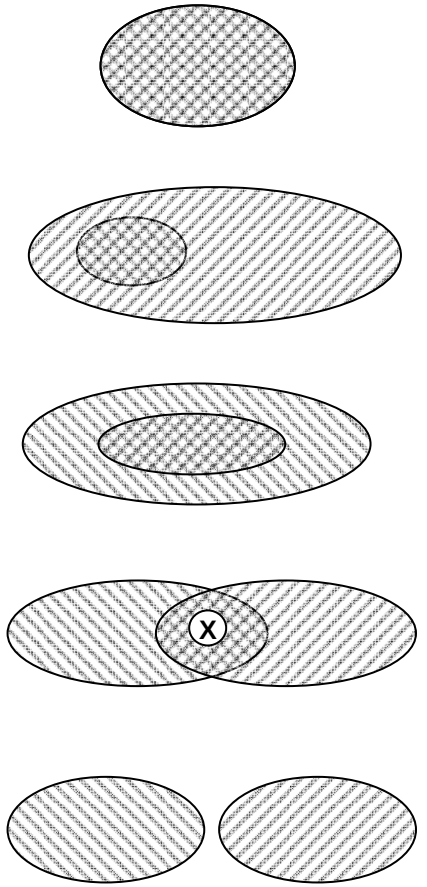
   $D_Q, D_R, O, M \models \forall x.\ (D_Q <= D_R)$

4. Intersection Match:

   $D_Q, D_R, O, M \models \exists x.\ (D_Q \wedge D_R)$

5. Non Match:

   $D_Q, D_R, O, M \models \neg\exists x.\ (D_Q \wedge D_R)$



Realization in VAMPIRE

Structure of a Proof Obligation for discovery

1. **Needed Knowledge Resources**
   - include Ontology Theory and Universe
   - Knowledge Base optionally

2. **Resource Description notion to be matched**
   - Request Resource & Result Resource
   - Only those notions that are to be matched

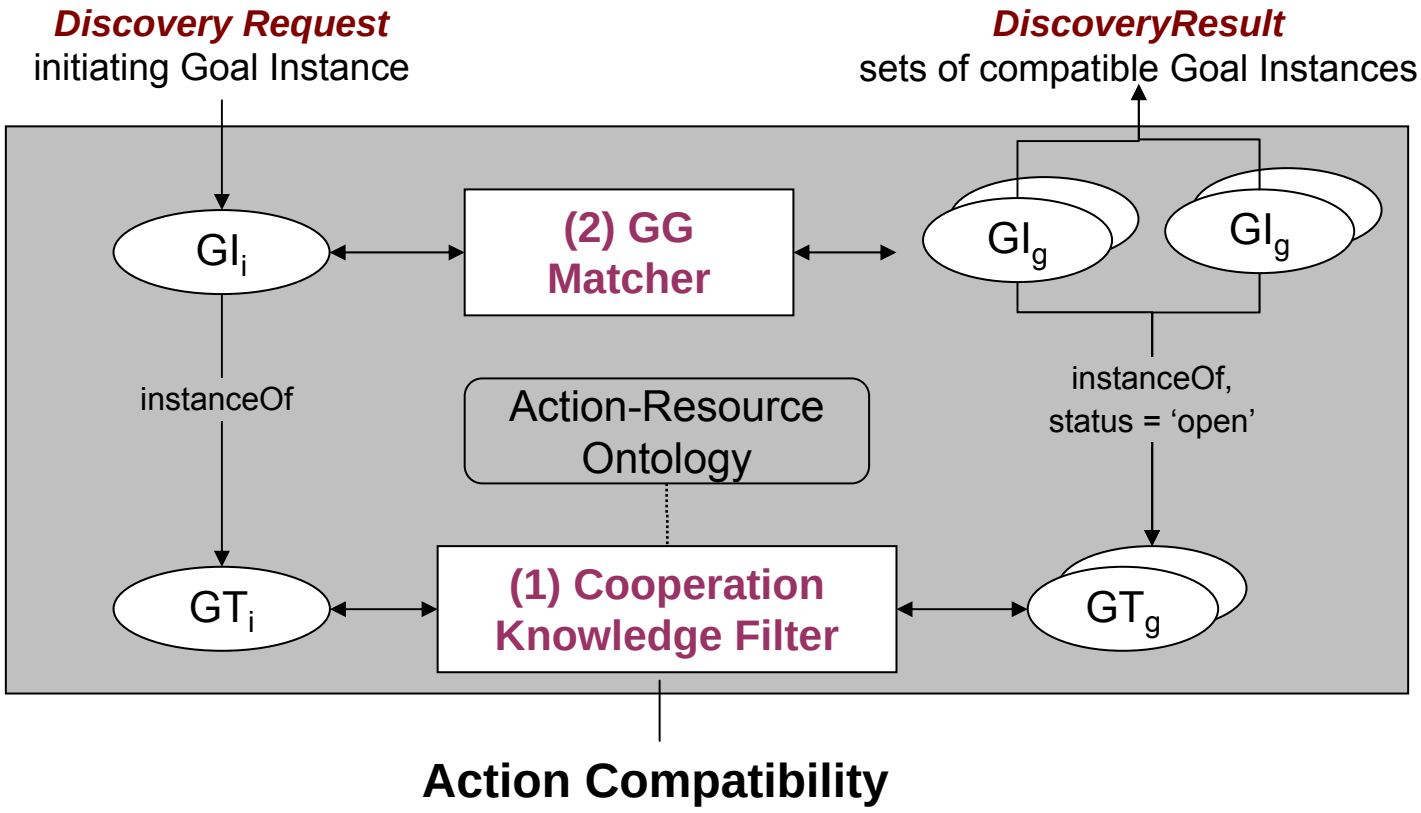
3. **Object Matchmaking notion**
   - Include as specified in the Discovery Request

=> *easy to generate dynamically*

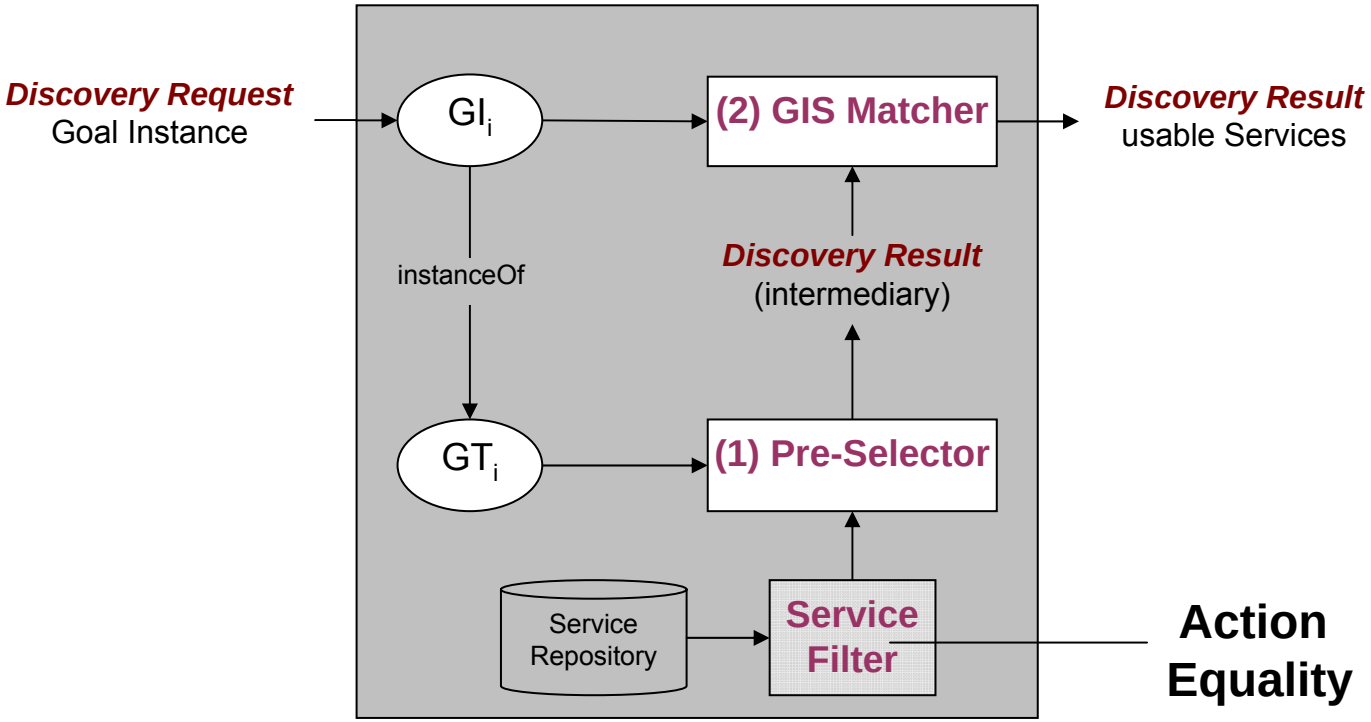
Partner & Service Discovery Components

- run independently, invoked by agents
- apply ARO & OMM as defined above
- Design Principles:
  1. Common Discoverer Architecture
  2. Modularized Functionality
  3. Layered Architecture (stepwise narrow search space)
  4. Reduction of expensive operations (efficiency)

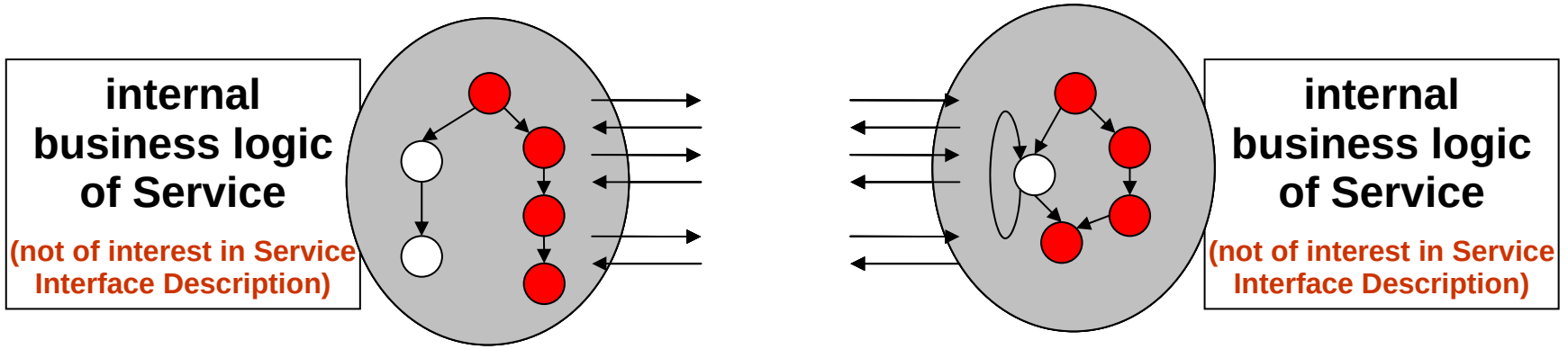
Partner Discoverer Architecture



Service Discoverer Architecture



Choreography Discovery



- a valid choreography (interaction protocol) exists if:
  1) **Information Compatibility**
     - compatible vocabulary
     - homogeneous ontologies
  2) **Communication Compatibility**
     - start state for interaction
     - a termination state can be reached without any additional input

Information Compatibility

If choreography participants have compatible vocabulary definitions:

- $\Omega_{in}(S1) \cup \Omega_{shared}(S1) = \Omega_{out}(S2) \cup \Omega_{shared}(S2)$
- determinable by Intersection Match

$$SI_{S1}, SI_{S2}, O, M \models \exists x. (\Omega_{S1(in \cup shared)}(x) \wedge \Omega_{S2(out \cup shared)}(x))$$

- more complex for multi-party choreographies

Prerequisite: choreography participants use homogeneous ontologies:

- semanticInteroperability(S1, S2, ..., Sn)
- usage of same ontologies in Service Interfaces or respective OO Mediators

Communication Compatibility

- Definitions (for "binary choreography" (only 2 services), more complex for multi-party choreographies)

Valid Choreography State:

$\omega_x(C(S1, S2))$ **if** informationCompatibility $(\Omega S1(\omega_x), \Omega S2(\omega_x))$

  - means: action in GT of S1 for reaching state $\omega_x(S1)$ satisfies condition in GT of S2 for reaching state $\omega_x(S2)$, or vice versa

Start State:

$\omega_\varnothing(C(S1, S2))$ **if** $\Omega S1(\omega_\varnothing) = \varnothing$ and $\Omega S2(\omega_\varnothing) = \varnothing$ and $\exists\ \omega_1(C(S1, S2))$

  - means: if initial states for choreography participants given (empty ontology, i.e. no information interchange has happened), and there is a valid choreography state for commencing the interaction

Termination State:

$\omega_T(C(S1, S2))$ **if** $\Omega S1(\omega_T) = \text{noAction}$ and $\Omega S2(\omega_T) = \text{noAction}$ and $\exists\ \omega_T(C(S1, S2))$

  - means: there exist termination states for choreography participants (no action for transition to next state), and this is reachable by a sequence of valid choreography states

- Communication Compatibility given if there exists a start state and a termination state is reachable without additional input by a sequence of valid choreography states

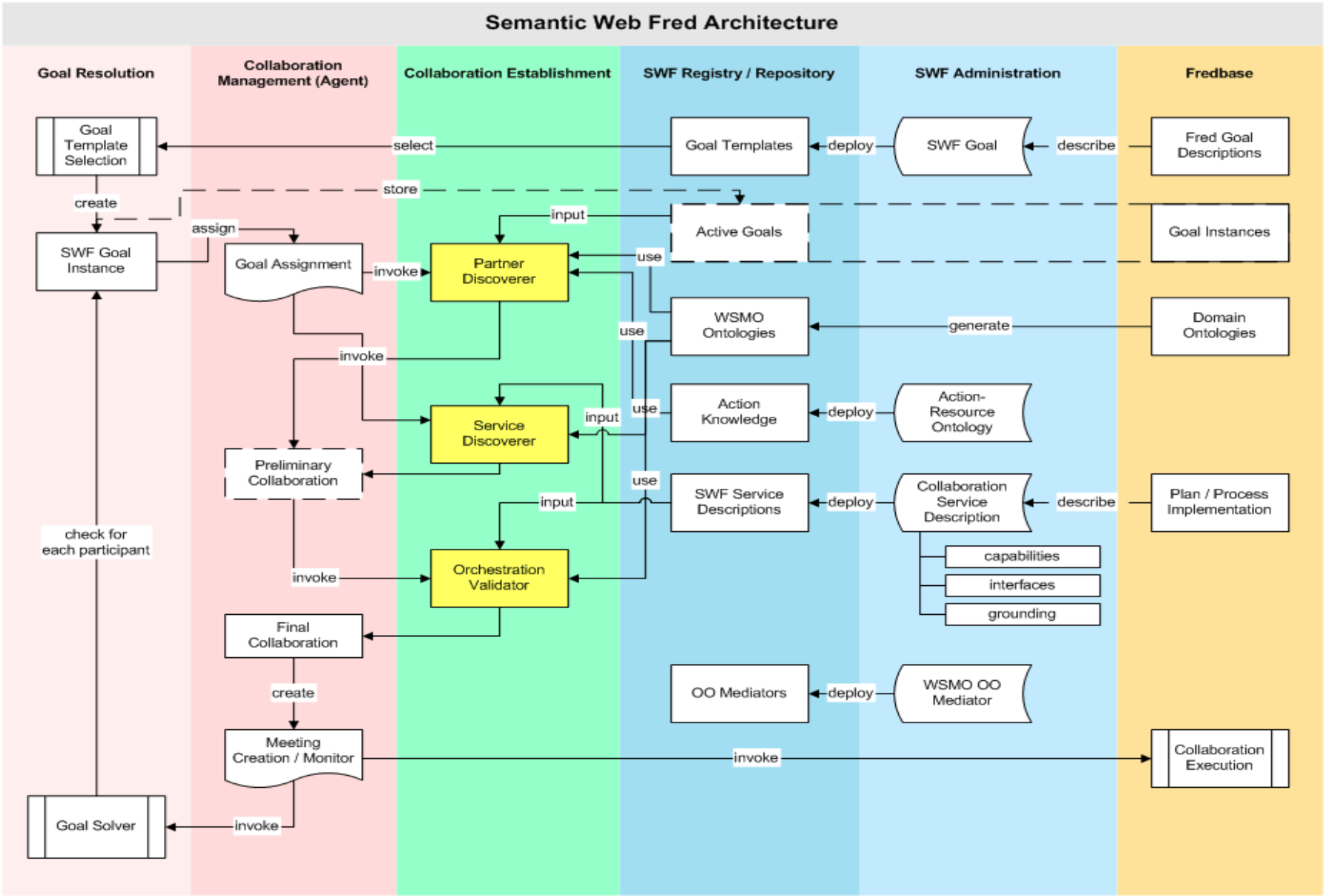
Orchestration Validation

discover valid choreography for all interactions that need to be performed for automated execution of a Collaboration

- **layered architecture / stepwise validation wrt efficiency:**
  - "multi-party choregraphy discovery"
  - Process:
    1. validate orchestration for CS of initiating agent
    2. validate orchestration of CS of each partner agent
  - for each binary choreography:
    1. determine information compatibility (less expensive operation)
    2. if (1), then determine communicatuion compatibility (more expensive operation)

- **under construction:**
  - choreography discovery prototype with VAMPIRE
  - Orchestration Validator implementation only checks on usage of homogeneous ontologies

Semantic Web Fred



Technologies Used

- **System Languages**
  - functional components in Java
  - GUIs in VB6
- **Smart Objects (ontology handling & management technology):**
  - Ontologies handled as Java objects
  - Ontology / SMO management facilities
- **UDDI Repository, conventional RDB as repository**
- **Collaboration Execution**
  - Meeting Rooms (central service, controls & monitors collaboration executions)
  - FIPA ACL as Collaboration Service Interaction Language
- **Web / Semantic Web / Web Service support**
  - Web Service usage via WSDL-Executor
  - WSMO registry(ies) alignment
  - Semantic Web Resource support (e.g. connection to YARS)

Conclusions

- Framework for Automated Collaboration on the Semantic Web
  - epistemology of collaborative interactions
  - coherent technology framework, combining most recent technologies
  - semantically enabled collaboration establishment / management
  - prototype realization & testing
- Main Results:
  - conceptual architecture & element definitions
  - Model of Agency, Goal & Service descriptions and usage
  - semantically enabled collaboration establishment
- Status of work:
  - conceptual / theoretic work nearly completed
  - development in SWF project is ongoing
  - expected finalization: end 2005 / spring 2006

Relation to Web Engineering

- WE aspects mostly in collaboration execution
  - Collaboration / Web Service invocation
  - automated information interchange over Web
  - decentralized / autonomous computation
  - ⇒ currently grounded to conventional Web (Service) technology (NOT what we want)

- insights in "Semantic Web Engineering":
  1. **"inference engines far away from industrial applicability"**
  - only limited / partial **Reasoning Support**
  - tremendous **deficiencies in stability, computation time, scalability**
  - **Reasoning Requirements still unclear** (light-weight object matchmaking vs. complex FOL reasoning)

  2. **"hide logics from users and system developers"**
  - semantic descriptions by **Knowledge Engineers**
  - exhaustive **tool support** required for users and system developers
  - **abandon logical expressivity** if it hampers automation