Agent-Oriented Software Development

John Mylopoulos
University of Toronto

SETN 2002, Thessaloniki,
April 11-12, 2002

What is Software?

- An engineering artifact, designed, tested and deployed using engineering methods, which rely heavily on testing and inspection for validation (***Engineering perspective***)
- A mathematical abstraction, a theory, which can be analyzed for consistency and can be refined into a more specialized theory (***Mathematical perspective***)

...but more recently...

- A non-human agent, with its own personality and behavior, defined by its past history and structural makeup (***CogSci perspective***)
- A social structure of software agents, who communicate, negotiate, collaborate and cooperate to fulfil their goals (***Social perspective***)

These perspectives will grow in importance -- in practice, but also SE research!

Why Agent-Oriented Software?

- Next generation software engineering will have to support open, dynamic architectures where components can accomplish tasks in a variety of operating environments.
- Consider application areas such as eBusiness, web services, pervasive and/or P2P computing.
- These all call for software components that find and compose services dynamically, establish/drop partnerships with other components and operate under a broad range of conditions.
- Learning, planning, communication, negotiation, and exception handling become essential features for such software components.

☛***... agents!***

Agent-Oriented Software Engineering

- Many researchers working on it.
- Research on the topic generally comes in two flavours:
  - ✓ Extend UML to support agent communication, negotiation etc. (e.g., [Bauer99, Odell00]);
  - ✓ Extend current agent programming platforms (e.g., JACK) to support not just programming but also design activities [Jennings00].
- We propose to develop a methodological framework for building agent-oriented software which supports ***requirements analysis***, as well as design.

What is an Agent?

- A person, an organization, certain kinds of software.
- An ***agent*** has ***beliefs***, goals (***desires***), ***intentions***.
- Agents are situated, autonomous, flexible, and social.
- But note: human/organizational agents can't be ***prescribed***, they can only be ***partially described.***
- Software agents, on the other hand, have to be completely specified during implementation.
- Beliefs correspond to (object) state, intentions constitute a run-time concept. For design-time, the interesting new concept agents have that objects don't have is...

☛***...goals!***

Why Worry About Human/Organizational Agents?

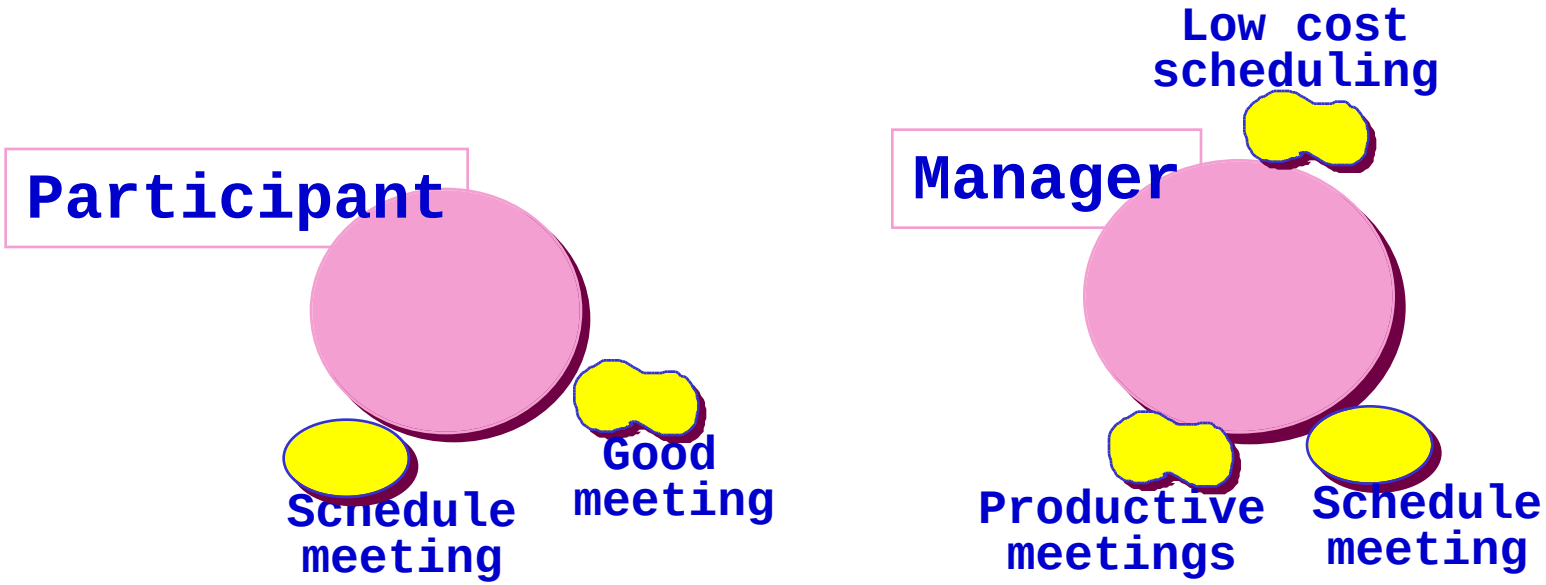
- Because their goals lead to software requirements, and these influence the design of a software system.
- Note the role of human/organizational agents in OOA, e.g., use cases.
- Also note the role of agents in up-and-coming requirements engineering techniques such as KAOS [Dardenne93].
- In KAOS, requirements analysis begins with a set of goals; these are analysed/decomposed to simpler goals which eventually either lead to software requirements, or are delegated to external agents.

The Tropos Methodology

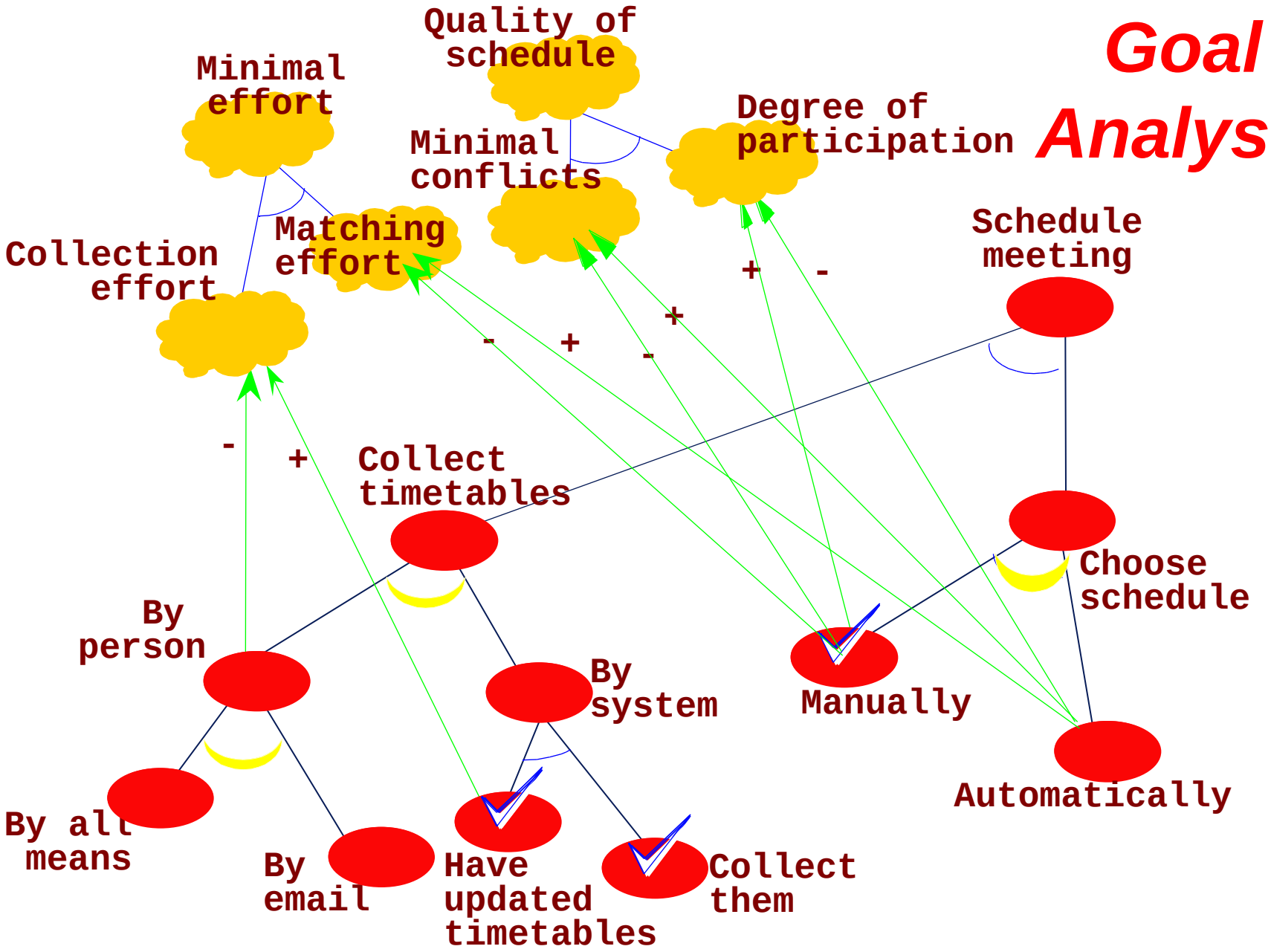
- We propose a set of primitive concepts and a methodology for agent-oriented requirements analysis and design. We adopt *i** [Yu95] as a modeling framework.
- Actors = Agents ∪ Positions ∪ Roles.
- We want to cover four phases of software development:
  - ✓ ***Early requirements*** -- identifies stakeholders and their goals;
  - ✓ ***Late requirements*** -- introduce system as another actor which can accommodate some of these goals;
  - ✓ ***Architectural design*** -- more system actors are added and are assigned responsibilities;
  - ✓ ***Detailed design*** -- completes the specification of system actors.

Early Requirements: Actors and their Goals

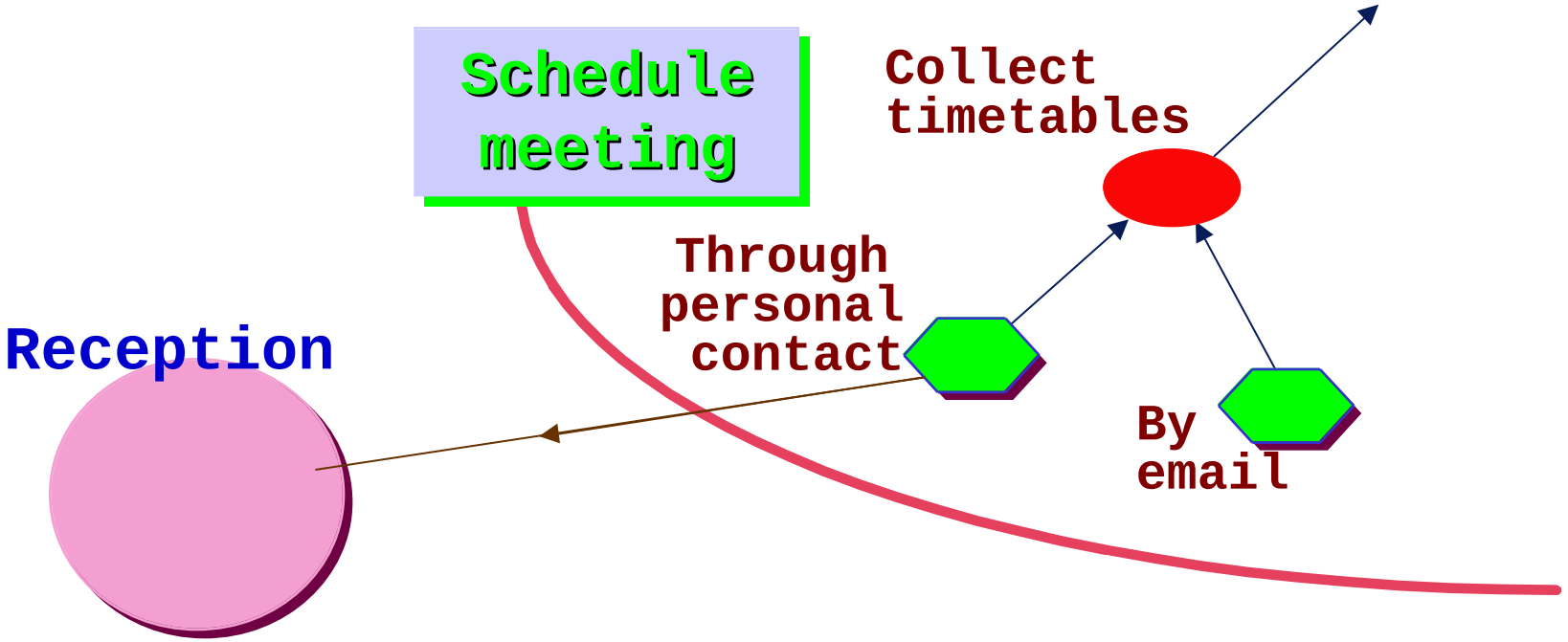
A social setting consists of actors, each having ***goals*** (and/or ***softgoals***) to be fulfilled.



Goal Analysis

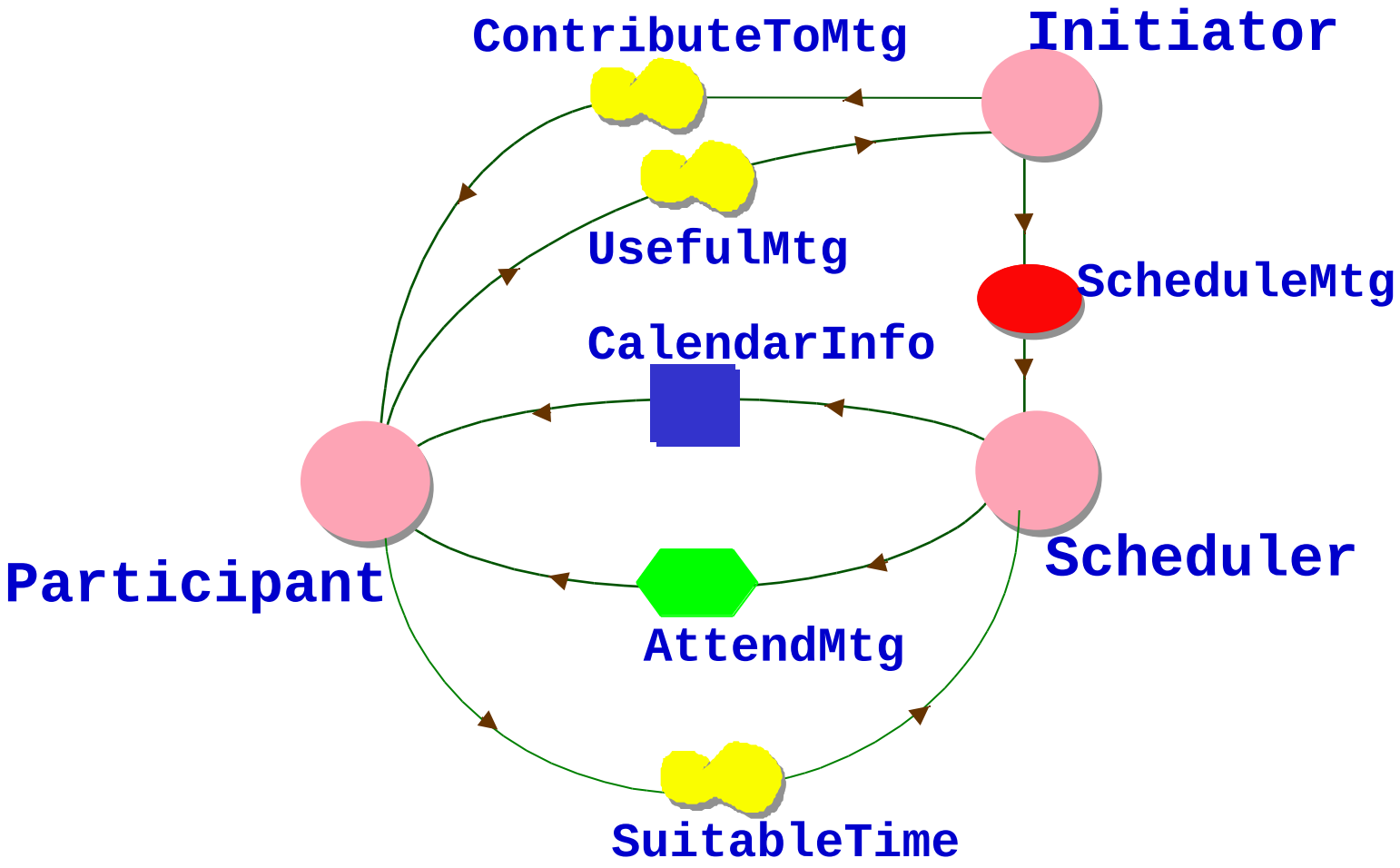


Actor Dependencies



Actor dependencies are intentional: One actor ***wants*** something, another is ***willing*** and ***able*** to deliver.

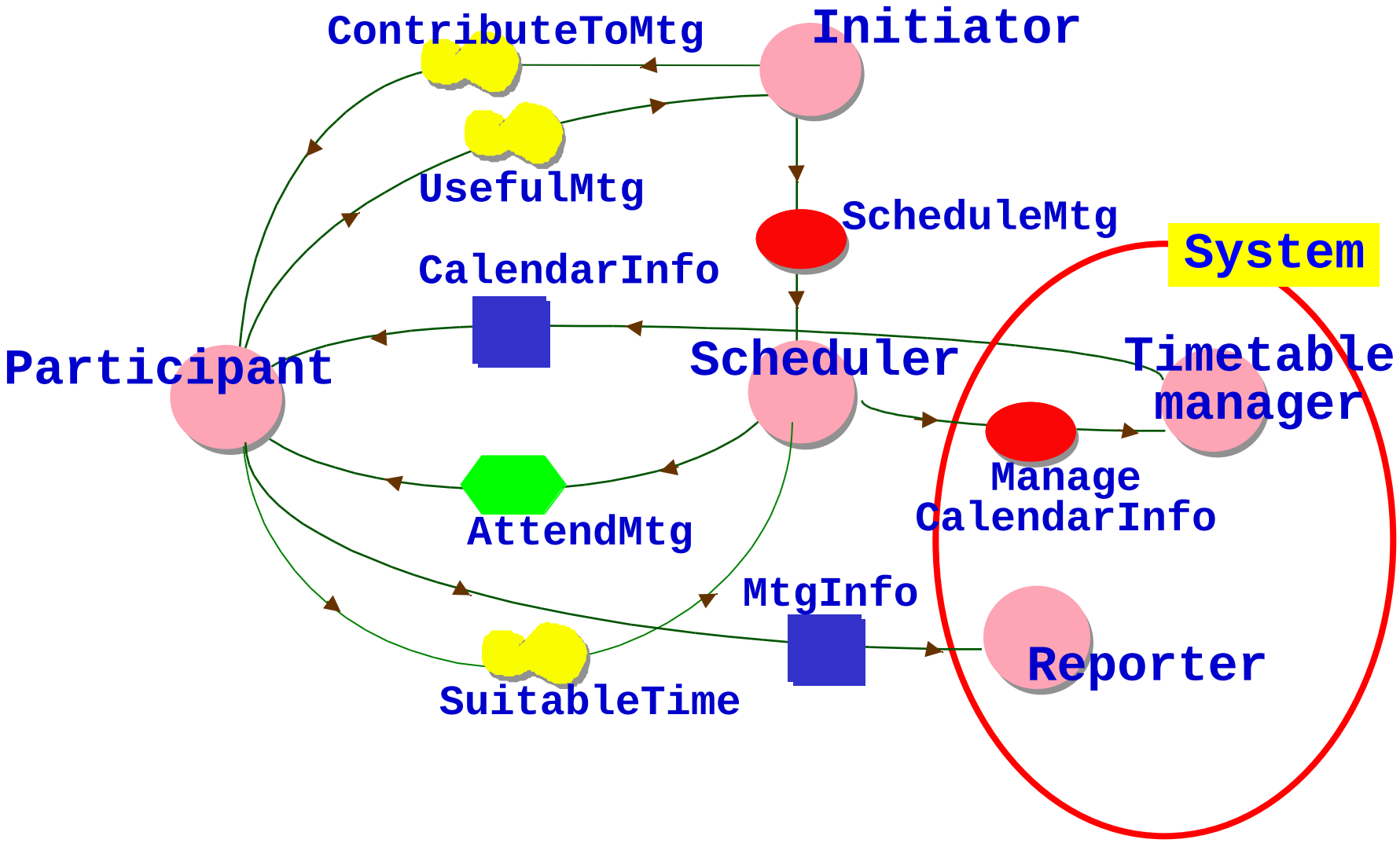
Actor Dependency Models



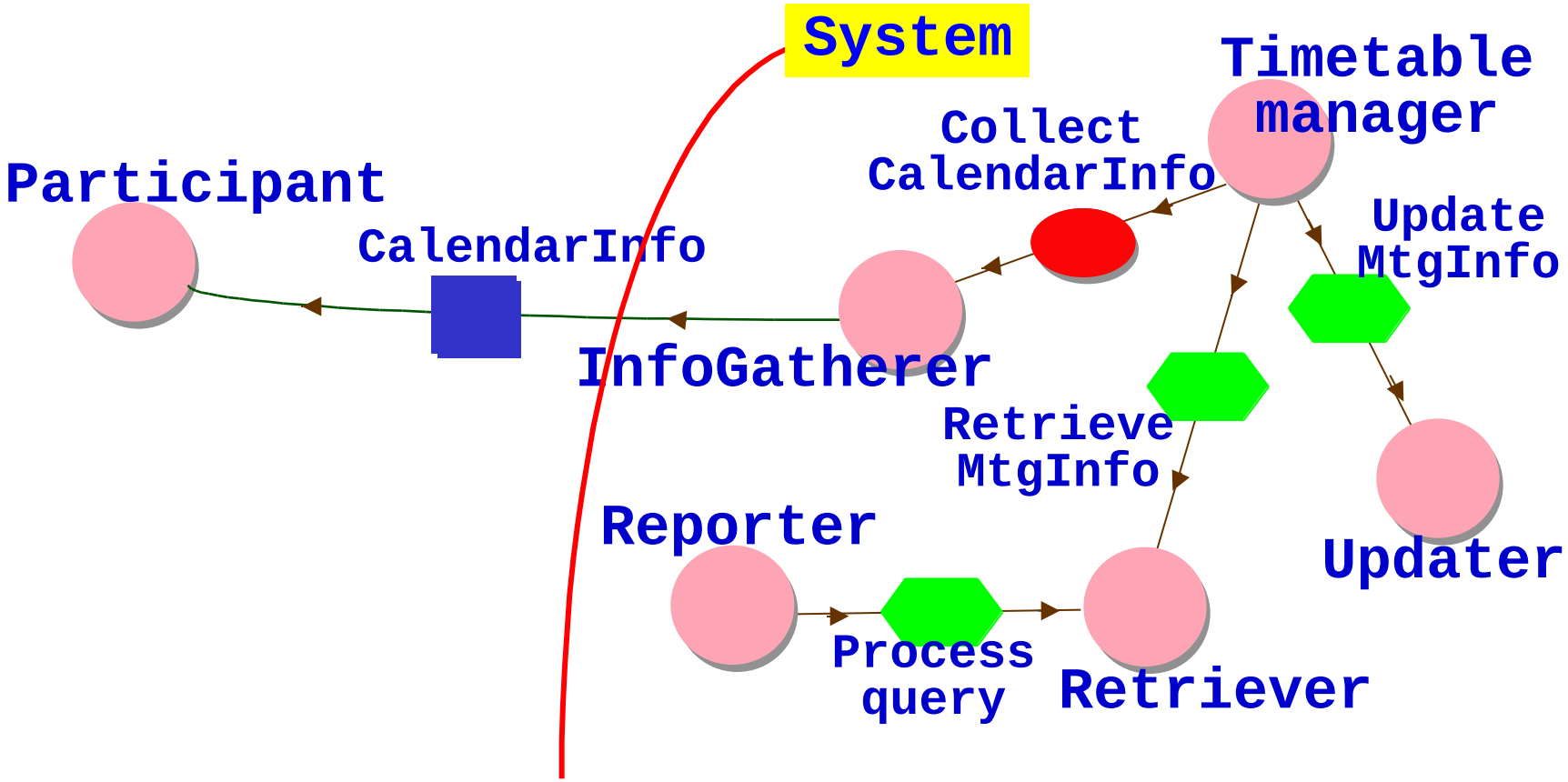
Using These Concepts

- During early requirements, these concepts are used to model external stakeholders (people, organizations, existing systems), their relevant goals and inter-dependencies.
- During late requirements, the system-to-be enters the picture as one or a few actors participating in *i** models.
- During architectural design, the actors being modelled are all system actors.
- During detailed design, we are not adding more actors and/or dependencies; instead, we focus on fully specifying all elements of the models we have developed.

Late Requirements with i*



Software Architectures with i*



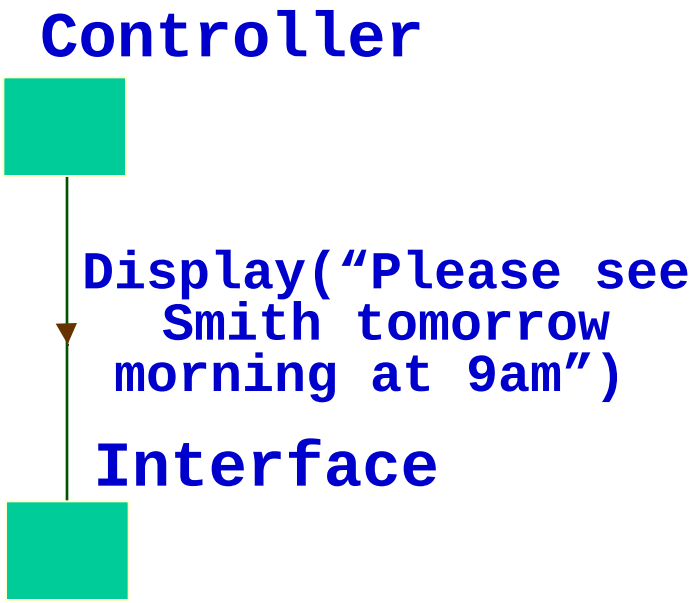
What is Different?

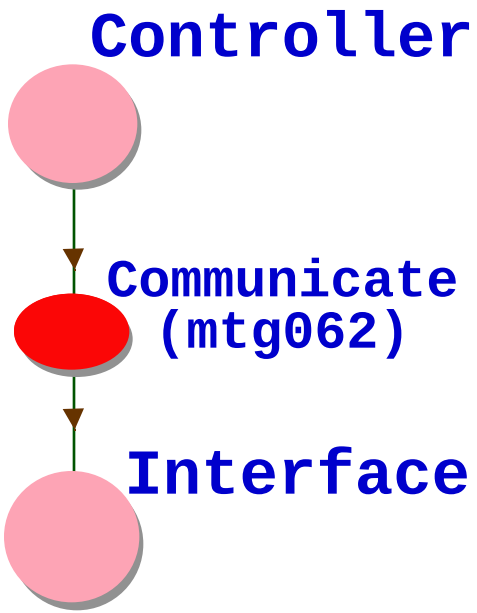
- Goal refinement extends functional decomposition techniques, in the sense that it explores alternatives.
- Actor dependency graphs extend object interaction diagrams in that a dependency is ***intentional***, needs to be monitored, may be discarded, and can be established at design- or run-time.
- In general, an actor architecture is open and dynamic; evolves through negotiation, matchmaking and like-minded mechanisms.
- The distinction between design and run-time is blurred.
- So is the boundary between a system and its environment (software or otherwise.)

Why is this Better (…Sometimes…)

- Traditionally, goals (and softgoals) are operationalized and/or metricized before late requirements.
- This means that a solution to a goal is frozen into a software design early on and the designer has to work within the confines of that solution.
- This won't do in situations where the operational environment of a system, including its stakeholders, keeps changing.
- This won't do either for software that needs to accommodate a broad range of users, with different cultural, educational and linguistic backgrounds, or users with special needs.

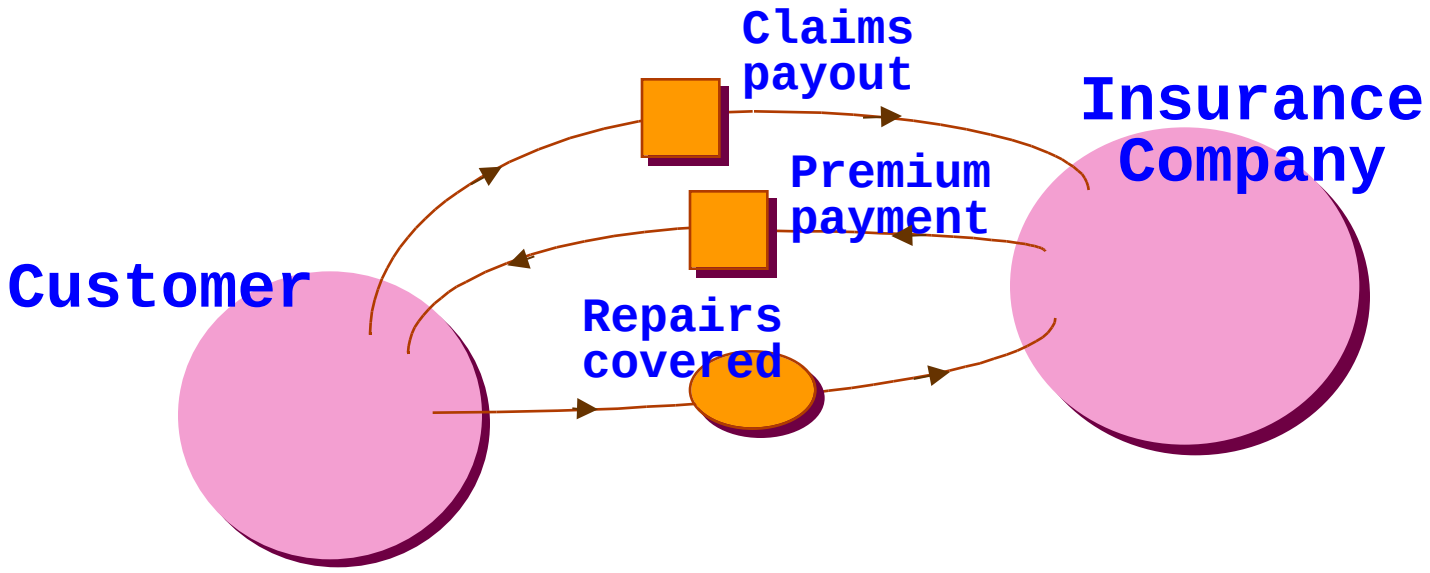
The Tale of Two Designs





Formal Tropos

- Each concept in a Tropos diagram can be defined formally, in terms of a temporal logic inspired by KAOS.
- Actors, goals, actions, entities, relationships are described statically and dynamically.



A Formal Tropos Example

```
Entity Claim
Has  claimId: Number, insP: InsPolicy,
 claimDate, date: Date, details: Text
Necessary date before insP.expDate
Necessary ( x)(Claim(x)   ●¬Claim(x)
 ¬RunsOK(x.insP.car))
end Claim

Action MakeRepair
   Performed by BodyShop
   Refines RepairCar
   Input cl : Claim
   Pre ¬RunsOK(cl.insP.car)
   Post RunsOK(cl.insP.car)...
```

A Goal Dependency Example

```
GoalDependency CoverRepairs
  Mode     Fulfil
  Depender Customer
  Dependee InsuranceCo
  Has cl: Claim
  Defined /* the amount paid out by the
  insurance company covers repair costs
  */
end RepairsCovered
```

Analysing Models

- Models are used primarily for human communication
- But, this is not enough! Large models can be hard to understand, or take seriously!
- We need analysis techniques which offer evidence that a model makes sense:
  - ✓ ***Simulation*** through model checking, to explore the properties of goals, entities, etc. over their lifetime;
  - ✓ ***Goal analysis*** which determine the fulfillment of a goal, given information about related goals;
  - ✓ ***Social analysis*** which looks at viability, workability,… for a configuraion of social dependencies.

Model Checking for Tropos

- Goal: Apply model checking to richer models than those that have been tried before.
- Approach
  - ✓ Definition of an automatic translation from Formal Tropos specifications to the input language of the nuSMV model checker [Cimatti99].
  - ✓ Verification of temporal properties of state representations of finite Tropos models.
  - ✓ Discovery of interesting scenarios that represent counterexamples to properties not satisfied by the specifications.
  - ✓ Model simulation.

Translation for CoverRepairs

VAR CoverRepairs : {no, created, fulfilled}

INIT CoverRepairs = no

TRANS CoverRepairs = no -> (next(CoverRepairs)=no |
next(CoverRepairs)=created)

TRANS CoverRepairs = created -> (next(CoverRepairs)=created |
next(CoverRepairs)=fulfilled)

TRANS CoverRepairs = fulfilled -> next(CoverRepairs) = fulfilled

TRANS CoverRepairs=no -> next(CoverRepairs = created ->
!RunOK)

TRANS CoverRepairs = created -> next(CoverRepairs = fulfilled
-> DamageCosts = fulfilled)

TRANS CoverRepairs = created -> next(CoverRepairs = fulfilled
<-> RunsOK)

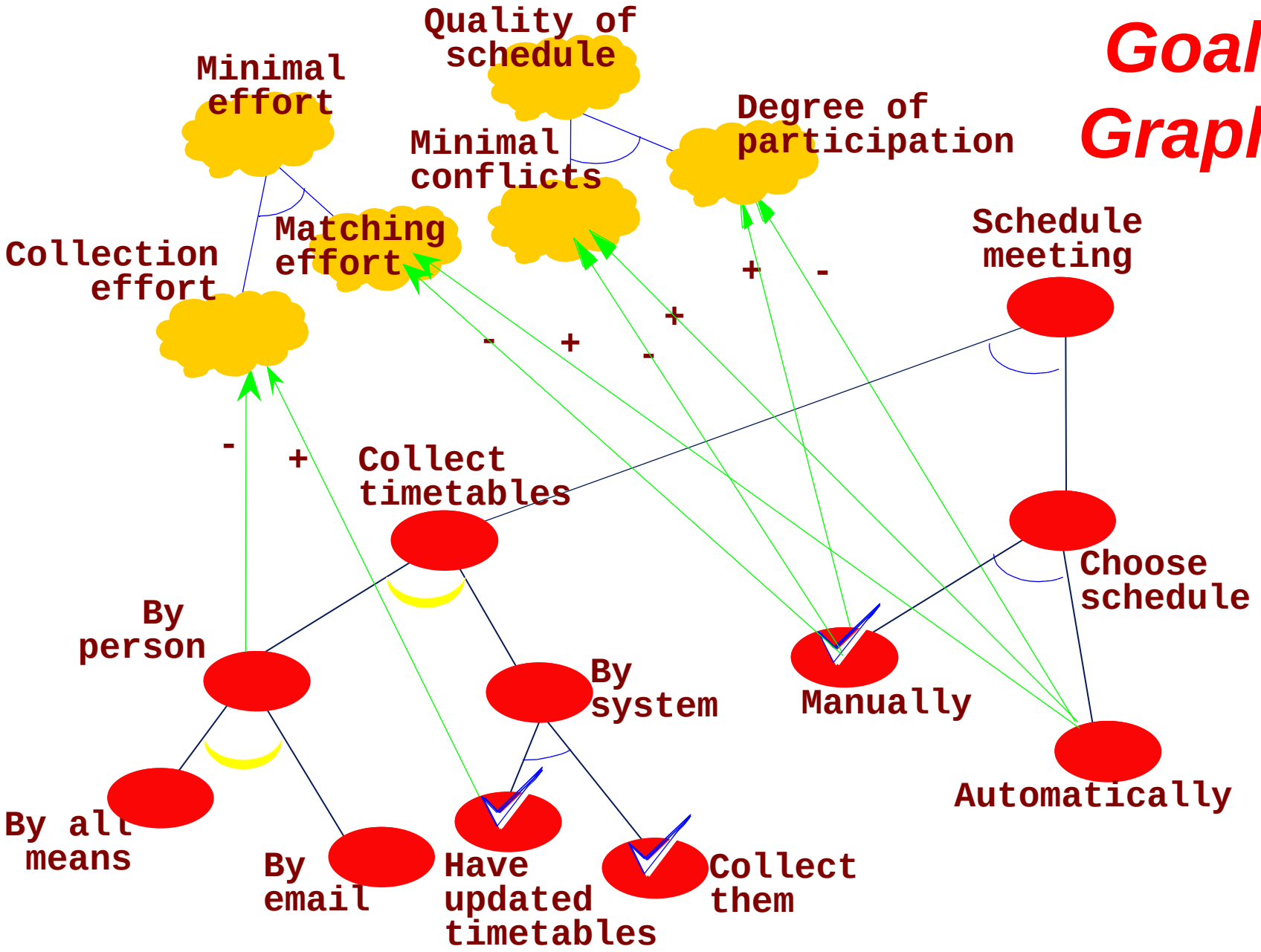
Goal Analysis

- Need to formalize the different types of goal relationships (AND, OR, +, -, etc.) and offer a (tractable) proof procedure.
- We use S(atisfied), D(enied) and don't assume that they are logically exclusive (remember, goals may be contradictory!)
- We offer several axioms for every goal relationship.

g1,g2,g3[AND({g1,g2},g3) ((S(g1) S(g2)) S(g3))]
g1,g2,g3[OR({g1,g2},g3) ((S(g1) S(g2)) S(g3))]
g1,g2[++(g1,g2) (S(g1) S(g2))]
g1,g2[+(g1,g2) g[(g≠g2 S(g) S(g1)) S(g2)]]

...more axioms for predicate D, goal relationships --, -...

Goal Graph



Goal Analysis (cont'd)

- Given a goal graph, we can instantiate these axioms into a collection of propositional Horn clauses, e.g.,

  g1,g2,g3[AND({g1,g2},g3) ((S(g1) S(g2)) S(g3))]

  ==> (S(collectTbl) S(chooseSchl)) S(scheduleMtg)

- We are also given some S and D labels for some goals, e.g., S(haveUpdatedTbl)
- There is an O(N) proof procedure which will generate all inferences from these axioms. Our proof procedure works as a label propagation algorithm.
- We are currently extending this algorithm to accommodate probabilities and criticalities for goals.

Tropos

- Project started in April 2000.

  http://www.cs.toronto.edu/km/tropos

- The team of participating researchers includes
  - ✓ UToronto (Canada): Fernandez Damian, Ariel Fuxman, Daniel Gross, Manuel Kolp, Linda Liu, Eric Yu;
  - ✓ UTrento/IRST (Italy): Paolo Bresciani, Paolo Giorgini, Fausto Giunchiglia, Eleonora Nicchiarelli, Anna Perini, Marco Pistore, Roberto Sebastiani, Paolo Traverso;
  - ✓ TUAachen (Germany): Matthias Jarke, Gerhard Lakemeyer.
  - ✓ FUPernambuco (Brazil): Jaelson Castro

Conclusions

- We have proposed a set of concepts and sketched a methodology which can support this paradigm.
- Agent-Oriented software development is an up-and-coming paradigm because of an ever-growing demand for customizable, robust and open software systems that truly meet the needs and intentions of their stakeholders.
- This is a long-term project, and much remains to be done.

References

- [Bauer99] Bauer, B., *Extending UML for the Specification of Agent Interaction Protocols.* OMG document ad/99-12-03.
- [Dardenne93] Dardenne, A., van Lamsweerde, A. and Fickas, S., "Goal–directed Requirements Acquisition", *Science of Computer Programming, 20*, 1993.
- [Iglesias98] Iglesias, C., Garrijo, M. and Gonzalez, J., "A Survey of Agent-Oriented Methodologies", *Proceedings of the 5th International Workshop on Intelligent Agents: Agent Theories, Architectures, and Languages* (ATAL-98), Paris, France, July 1998.
- [Jennings00] Jennings, N. R., "On Agent-Based Software Engineering", *Artificial Intelligence, 117,* 2000.
- [Odell00] Odell, J., Van Dyke Parunak, H. and Bernhard, B., "Representing Agent Interaction Protocols in UML", *Proceedings of the First International Workshop on Agent-Oriented Software Engineering* (AOSE-2000), Limerick, June 2000.
- [Yu95] Yu, E., *Modelling Strategic Relationships for Process Reengineering*, Ph.D. thesis, Department of Computer Science, University of Toronto, 1995.