Requirements Models at Design- and Runtime

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Abstract

We review the history of requirements models going back to the seminal works of Douglas Ross on SADT. We also discuss the main ingredients of modeling languages in general, and requirements modeling languages in particular, including the set of primitive concepts they are founded on (their ontology), the language they offer for building models, and their semantics, defined in terms of an entailment relation over models. Finally, we sketch some of the desirable features (. . . "requirements") of design-time and runtime requirements models and draw conclusions about their similarities and differences.

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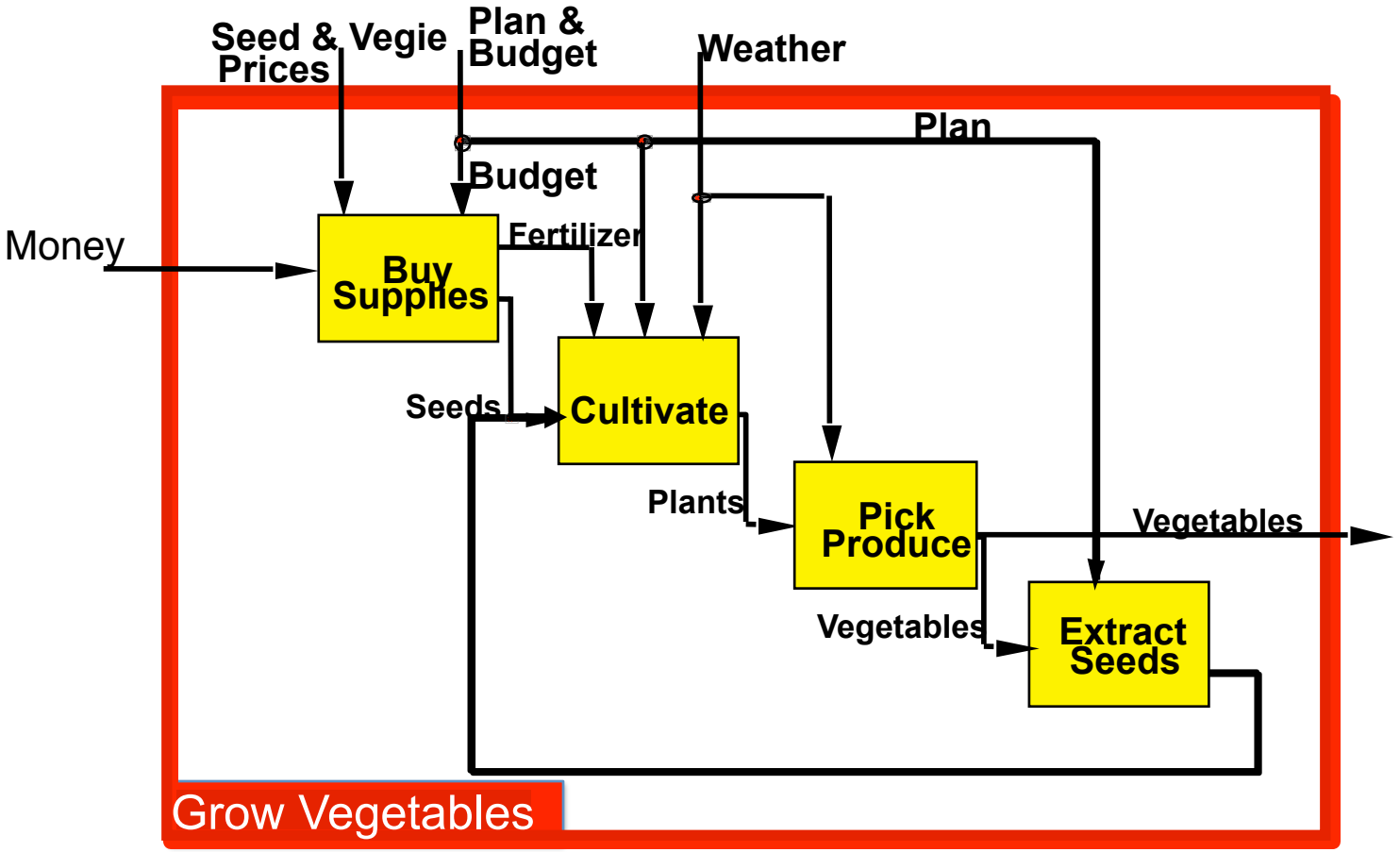
Requirements Engineering (RE)

- Concerned with the elicitation, analysis and refinement of stakeholder requirements in order to produce a specification for a system-to-be.
- Founded on seminal works by Douglas Ross, Michael Jackson and others in the mid-70s.
- Unique research area within CS because its task is not to solve problems, but rather to ***define*** ones.
- Interesting area because stakeholder ("early") requirements are necessarily vague, informal, self-contradictory, and more (... in short, "scruffy"), but they are requirements none-the-less.

Origins

- Requirements are activities/functions the system-to-be will perform within its operational environment (Douglas Ross, c.1977).



The Requirements problem

- In its original formulation [Jackson95], a requirements problem consists of finding a ***specification*** S for a given set of ***requirements*** R and ***indicative environment properties*** E such that

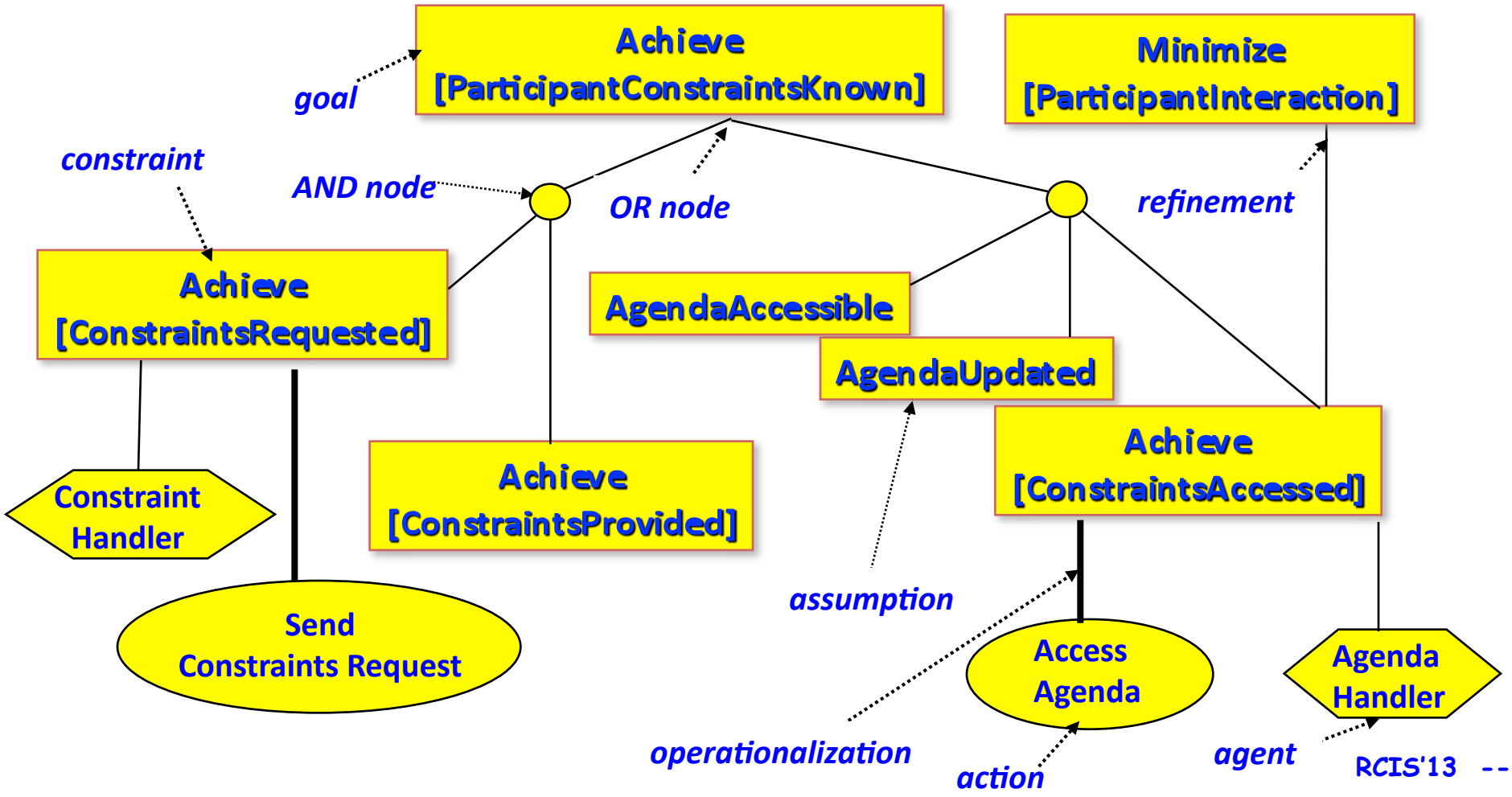
$$E, S \vdash R$$

meaning: "… satisfaction of the requirements can be deduced from satisfaction of the specification, together with the environment properties…" [Jackson95]

- Solution through refinement (as in program refinement): Start with requirements and keep refining them to eliminate mention of non-executable elements.

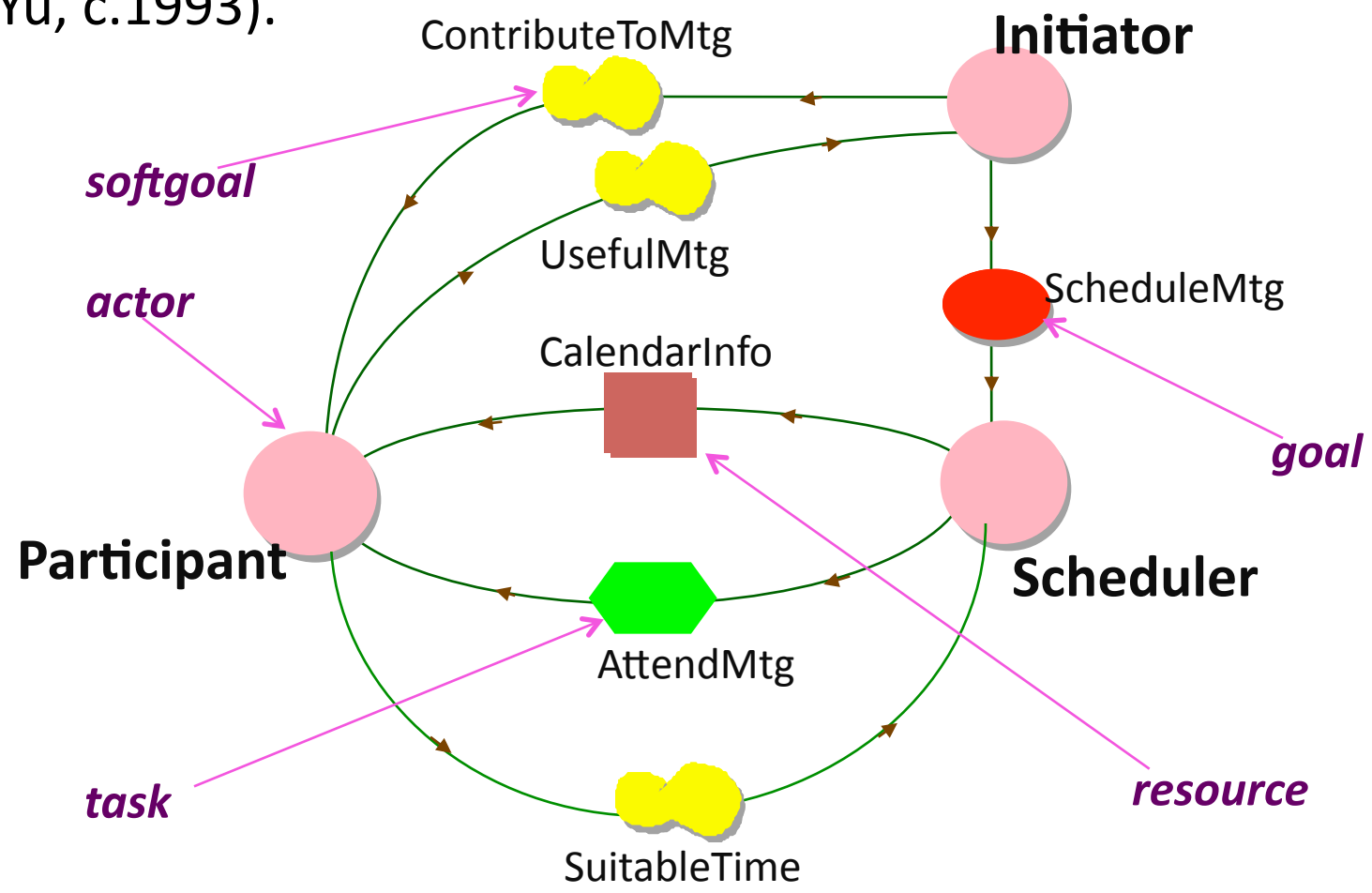
Requirements as goals

- Requirements are now goals and (requirements) problem solving amounts to incremental AND/OR goal refinement (Axel van Lamsweerde, c.1993).



Stakeholders as Actors

- Models now include stakeholders, represented as actors, who have goals and rely on others for their fulfillment (Eric Yu, c.1993).



Interesting ideas

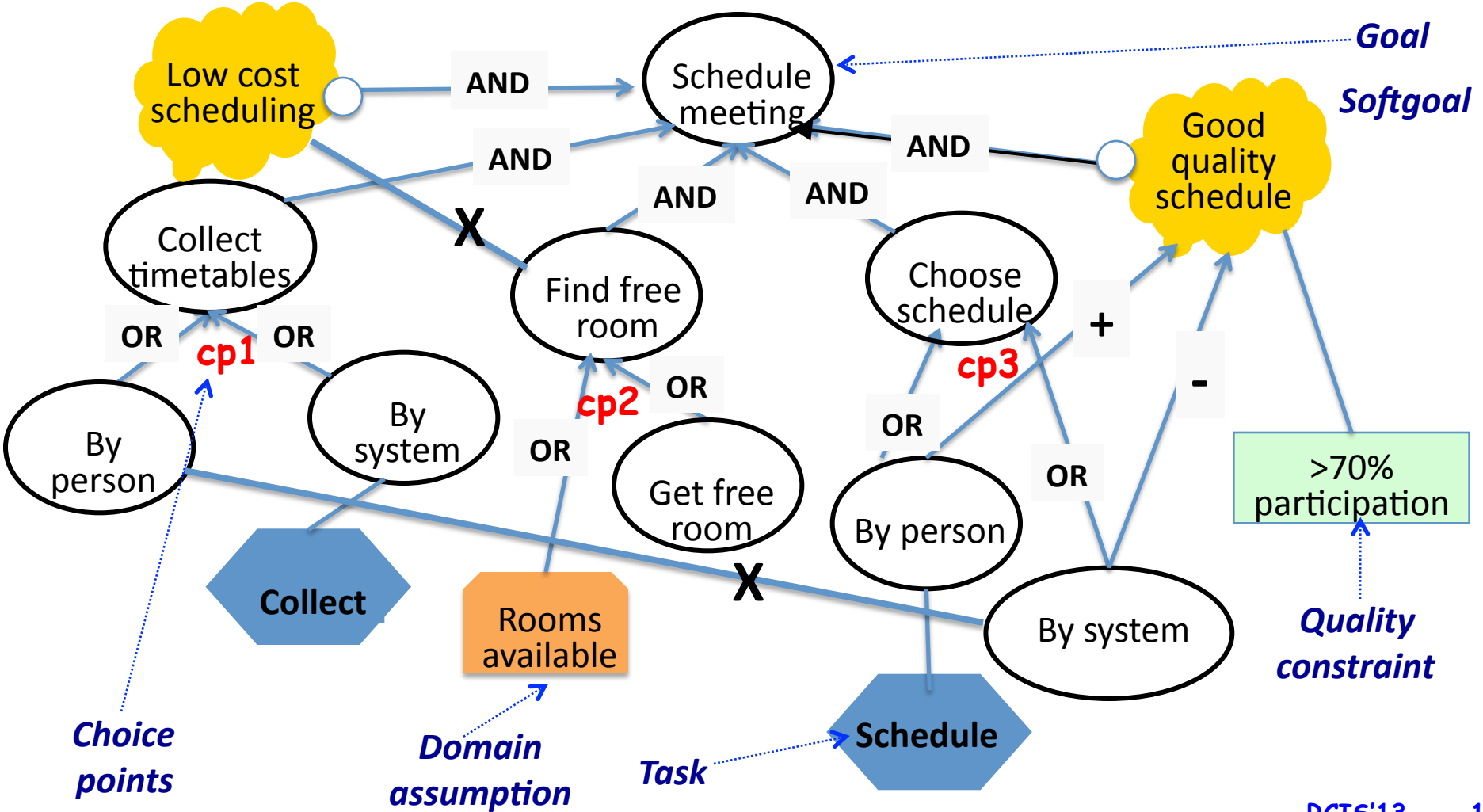
- Requirements derived from models of the ***domain*** (Ross).
- Requirements and ***specifications*** are different things, though logically related (Jackson).
- Requirements as ***goals*** stakeholders want (vanLamsweerde).
- The requirements problem is a ***social*** problem (Yu).
- The requirements problem is solved through problem ***refinement*** (all), and this refinement has many forms: activity decomposition (Ross), abductive inference (Jackson), goal refinement (vanLamsweerde), social delegation (Yu).
- With goal models and refinement, you are not exploring a design, but rather a design ***space***.

Lessons learned

- Requirements modelling languages (RMLs) should be ***informality-tolerant***, therefore not expressive (e.g., propositional languages will do).
- RMLs should be ***inconsistency-tolerant***.
- RMLs should be ***logics*** with a well defined semantics, e.g., an entailment relation (|=).
- RMLs are (… should be) triples, consisting of an ***ontology*** of primitive concepts, a ***language*** for making statements about requirements and the domain, and an ***entailment*** relation.
- The ontology chosen for a RML impacts greatly elicitation, modelling and analysis.

Goal models circa 2013

- Goals can be mandatory/nice-to-have, can have priorities [Jureta08], probabilities [Letier04], utility [Liaskos13], …



Reasoning with design-time goal models

- What-if: Assuming that some goals have been fulfilled/ denied, infer the status of the rest of the goal model.
- Satisfiability: Is there a specification for a given goal model?
- What-if reasoning can be handled with simple label propagation algorithms, satisfiability requires a SAT solver [Sebastiani04].
- Reasoning with preferences, probabilities and utilities requires more than a SAT solver, e.g., AI planners [Liaskos10], SMT solvers, …

What do these models tell us?

- They give us alternative specifications (sets of functions, qualities and assumptions) for fulfilling requirements.
- If someone wants a design that fulfills requirements in multiple ways (e.g., product families, flexible business processes, adaptive software systems) then our solution and implementation should encompass multiple specifications, not just one.
- These are ***design-time*** goal models, of no apparent use during runtime and/or evolution.

Adaptive Software Systems

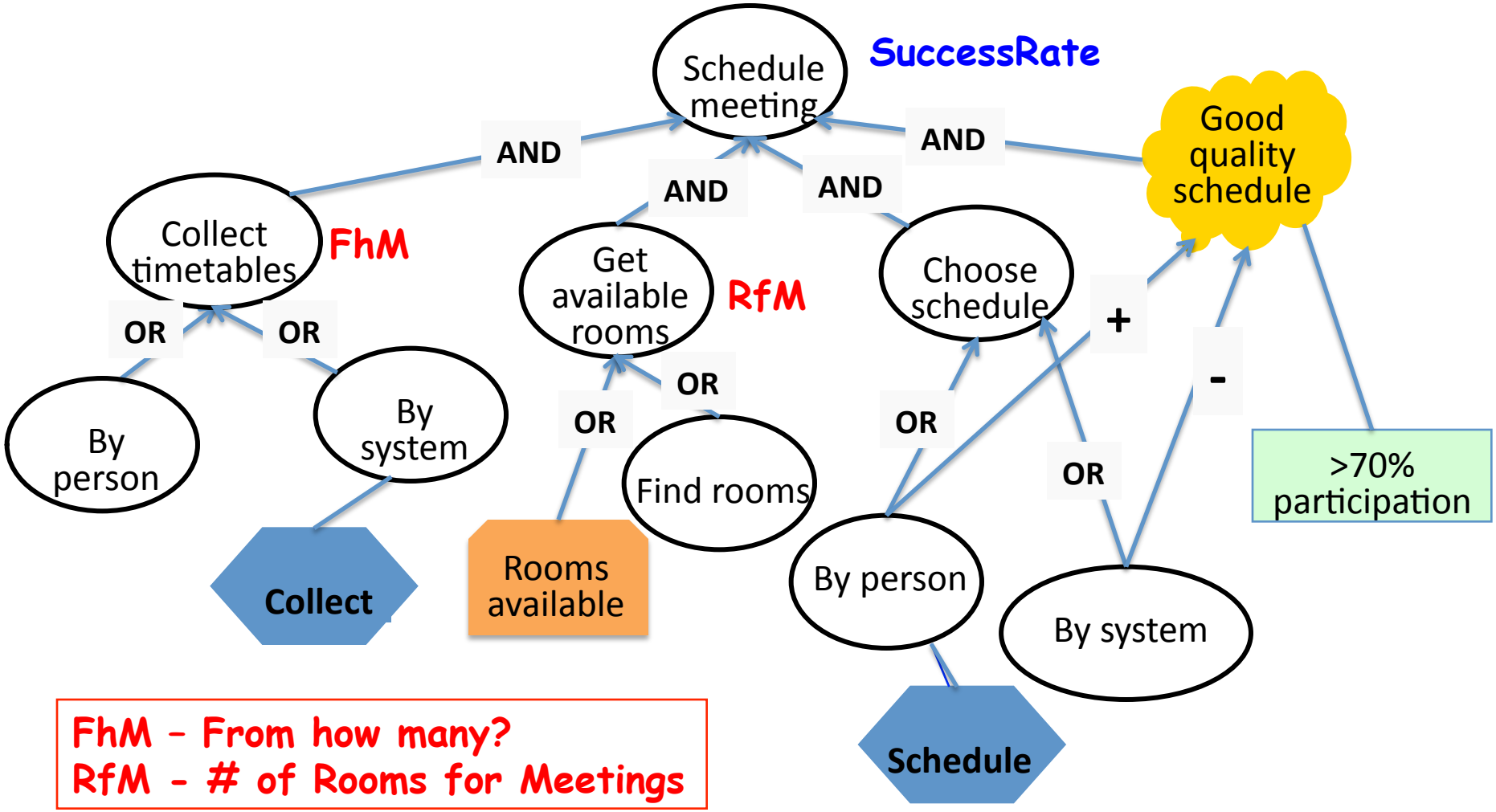
- Software systems increasingly operate within volatile environments where the one constant is uncertainty: cyber-physical systems, socio-technical systems, …
- In response, there has been growing interest in adaptive software that monitors its own performance and the environment, and adapts if its requirements fail.

☞ Need to monitor requirements, but how?

- Two approaches: (a) Monitor design artifacts (code, architecture, business process) and draw conclusions about requirements, (b) monitor requirements.

… We opt for the latter, of course!

Extended goal models [Souza12]



Requirements for adaptation

- Awareness requirements [Souza11]: Impose constraints on the success/failure of other requirements

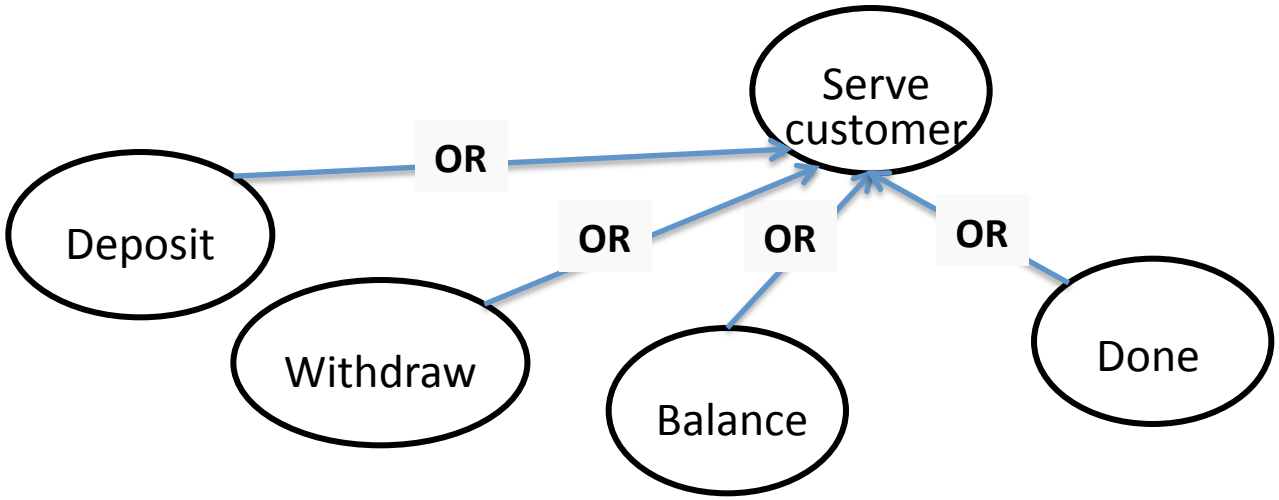
  e.g., "Requirement R should not fail more that 5% of the time during any 1-month period"

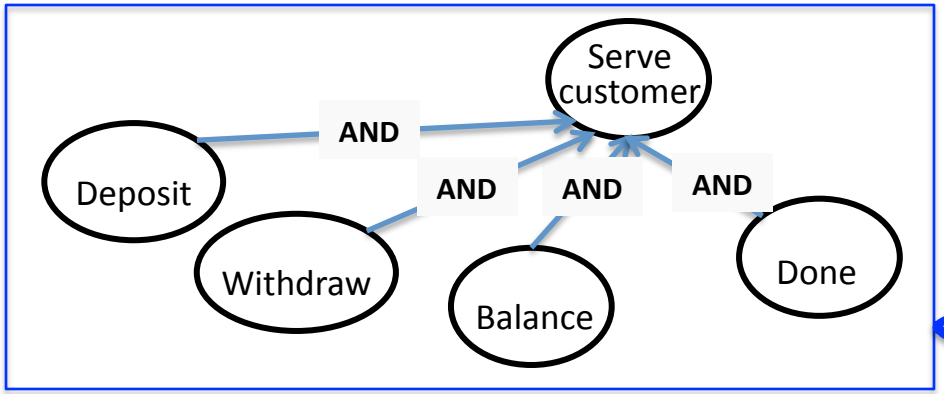
- Evolution requirements [Souza12]: When certain conditions apply, specify changes to other requirements

  e.g., "If requirement R fails 3 times in a row, drop it (it is no longer a requirement).

Runtime models – motivation

- Yiqiao Wang [Wang07] used goal models to support monitoring and diagnosis for adaptive systems.
- Excerpt from her ATM example goal model

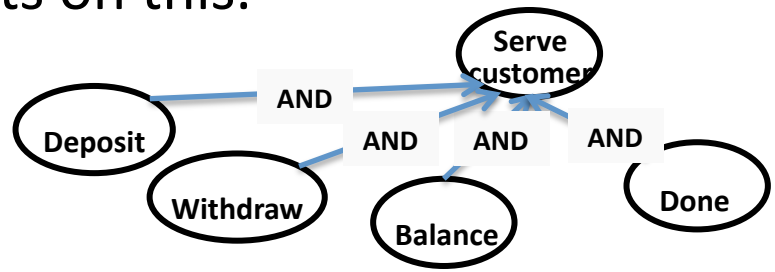




Wait a minute …
Why not …??

Design-time vs runtime models

- Design-time models are intended to help us determine ***required functionality*** for the system-to-be.
- Runtime models are intended to help us ***monitor behaviour*** of the system and take corrective action, if necessary.
- We know how to (formally) reason with design-time models.
- How do we reason with runtime ones? For example, if we know that an instance of D, satisfied, is followed by 2 instances of W, both satisfied, and two instances of B, one satisfied, the other pursued, what can we infer about their parent instance of SC?
- See [Morandini09] for early results on this.



Towards Runtime Models

- We augment goal models, so that they capture:
  - ✓ Behaviour – possible sequences of actions for fulfilling a goal;
  - ✓ State – possible states of a goal instance; current state of each goal instance;
  - ✓ History – the state history of all instances of a goal

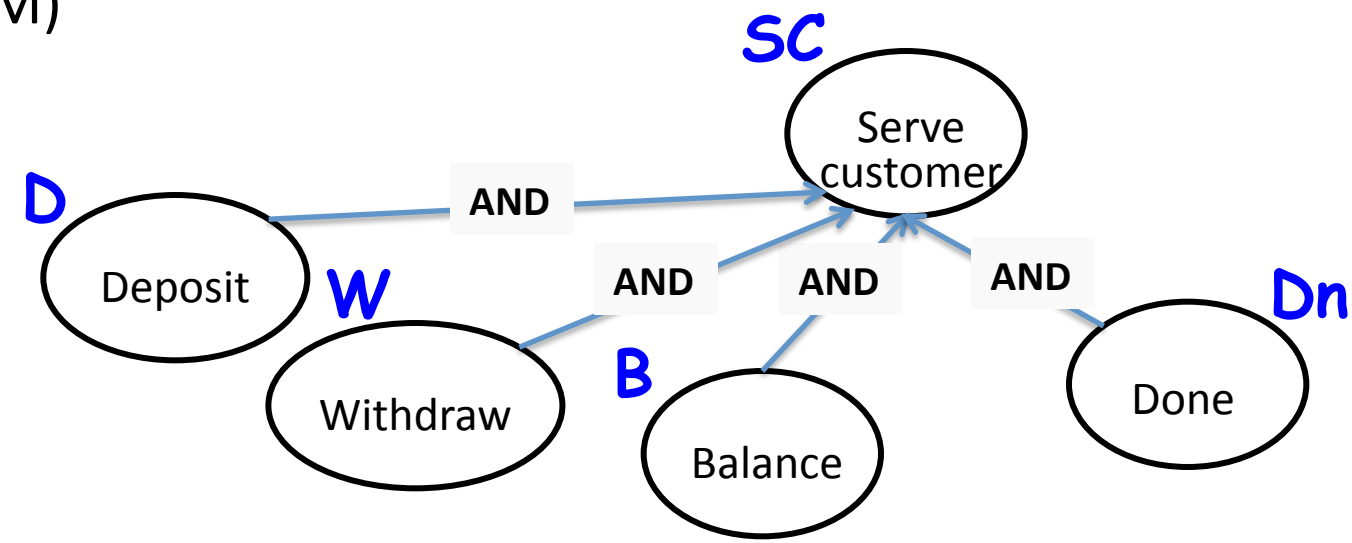
Behaviour

- Defined by annotating every non-leaf goal with a shuffle regular expression, e.g.,

$$annot(SC) = (D \mid W \mid B)^{+} \; ; \; Dn$$

$$\ldots \text{ or } \ldots ((D \mid W)^{+} \# B^{+}) \; ; \; Dn$$

- The result of such annotations is a behavioural goal model (BGM)

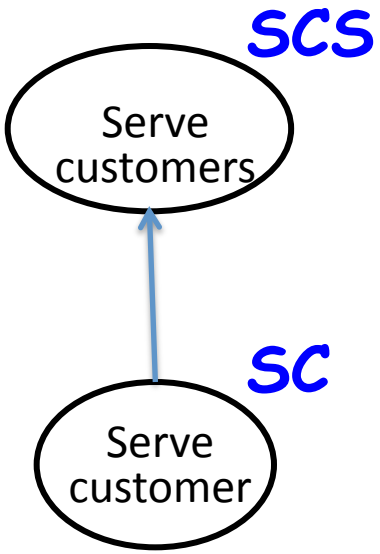


Behaviour – Shuffle

- Means exactly what you see …
- If w1 = abb and w2 = acbb,
  then w1 # w2 consists of strings
  like aabcbbb, aacbbbb, … lot's of them!
- More interestingly, shuffle closure …

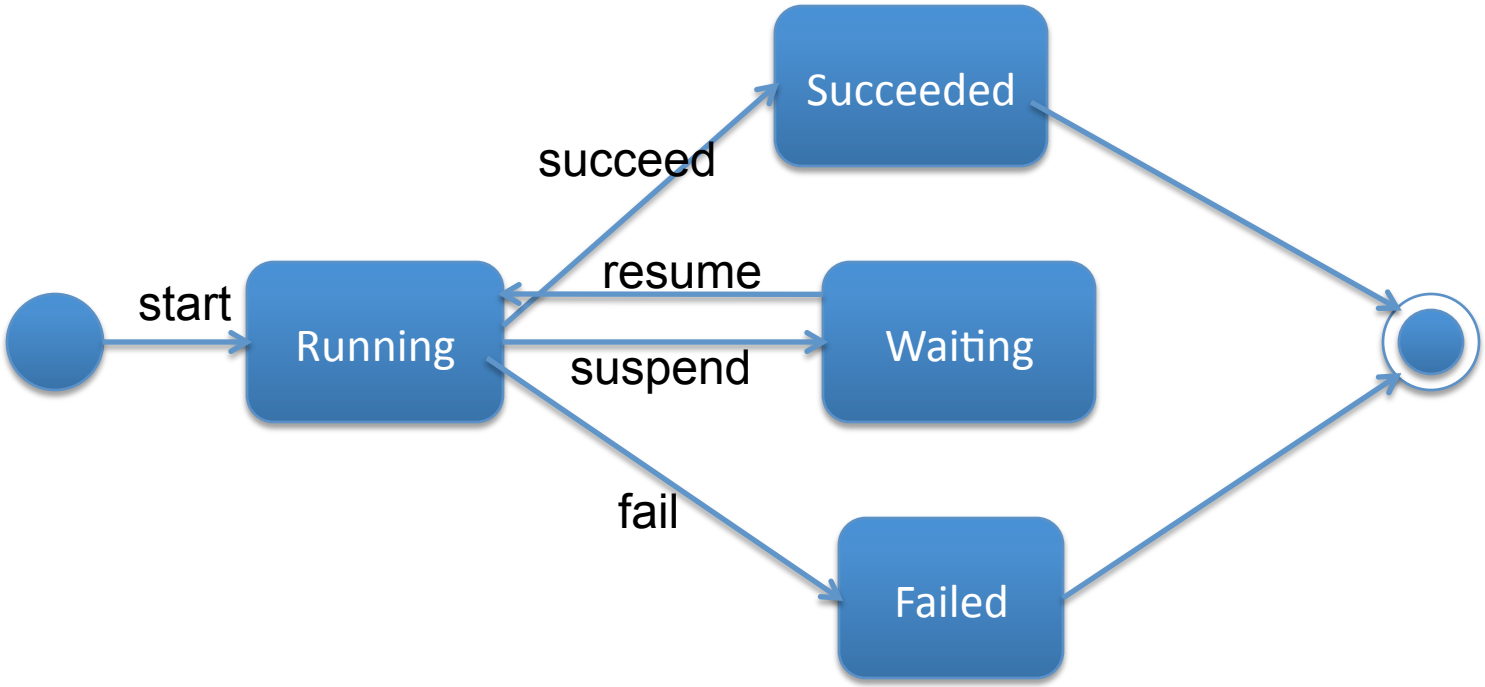
  $w^{\#} = w \mid w\#w \mid w\#w\#w \mid \ldots$

  amounts to unbounded concurrency
- For example, $SCS = SC^{\#}$
- Recognition for shuffle regular expressions
  is PTIME



State

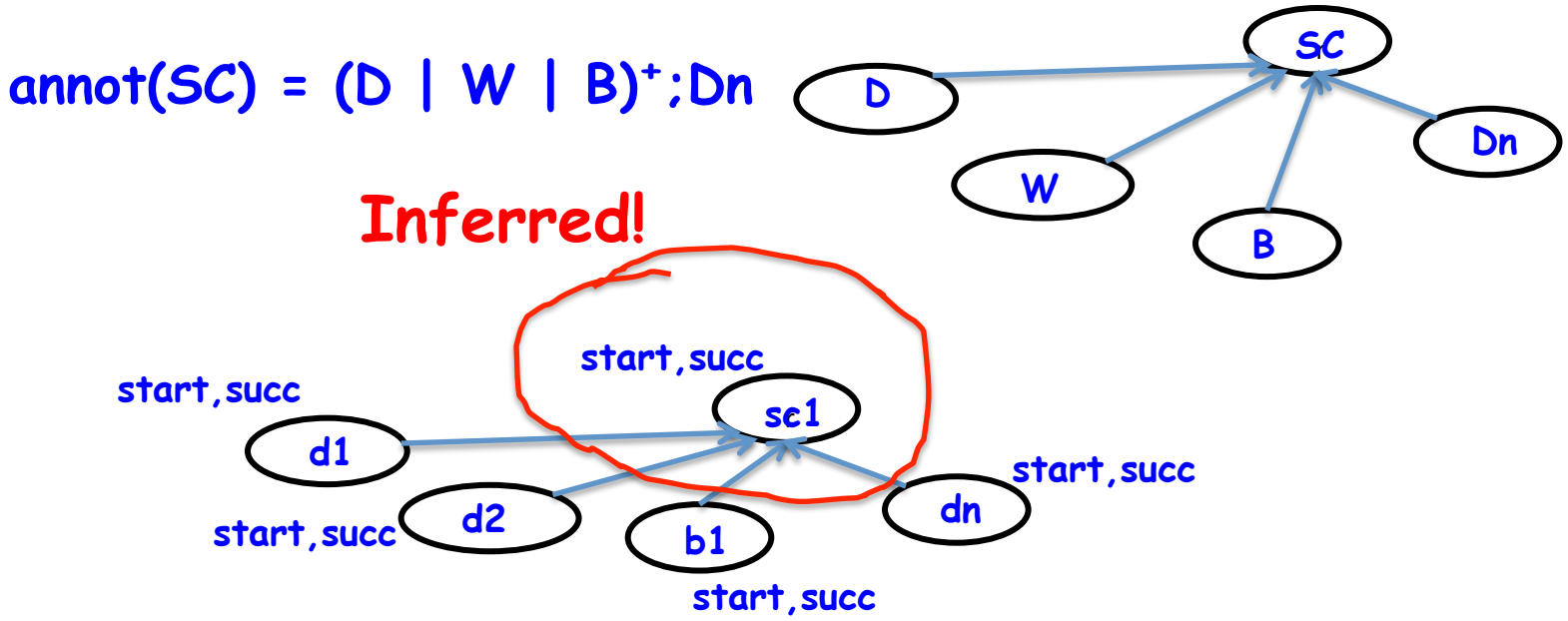
- We can use FSMs, such as the following one (for goals).
- Every goal instance can be in one of these states. …



History

- At runtime, a system ***trace*** is generated marking state transitions for ***leaf*** goal instances

d1.start,d1.succ,d2.start,…,dn.start,dn.succ



Reasoning with runtime goal models

- Recognition: Given a trace and a BGM, determine if the trace is legal.
- RGI construction: Given a trace and a BGM, infer the states of non-observable goal instances and construct a corresponding goal instance model.
- Diagnosis: Assume a class of possible failures; given a trace and a BGM, determine if there is a failure; if so, determine all possible root causes.

Summary

- Unlike their design cousins, runtime requirements models need to capture behaviour, state and history.
- Reasoning for such models is founded on recognition problems for formal languages and automata, rather than satisfiability.
- The ever-growing demand for flexibility, adaptability, customizability, etc. dictates the use of requirements models both at design time, runtime and throughout the lifecycle of a software system.

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