Looking into the Crystal Ball: Requirements Evolution over Time

Alicia M. Grubb, Marsha Chechik
{amgrubb, chechik}@cs.toronto.edu

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Motivating Example

Goal: Evaluate waste management infrastructure

Intentions: Wants to be green and satisfy customer

Options: Build Green Centre
         Build Landfill / Dump (large, small)

Approach: Choose correct alternative(s) using goal modeling.
Waste Management Example

Manage City Waste
- Use Current Dump
  - or
  - Use New Dump
    - or
    - Build Large Dump
      - or
      - Build Small Dump
        - or
        - Process Green Waste
          - and
          - Build Green Centre

Actor
- Goal
- Task
- Soft Goal
- Resource

and

Decomposition
depends
makes

Dependency
Contribution
Waste Management Example
Waste Management Example

- City
  - Update Truck Route
  - Upgrade Trucks
  - Space in Dump
    - Use Current Dump
    - Use New Dump
    - Manage City Waste
      - Comply with Standards
        - Build Large Dump
          - Purchase Land
            - Have Workers Union Contract
        - Build Small Dump

- Citizen
  - Quality of Waste Separation
    - Environmental Concern
      - Willingness to Separate Waste
  - Positive City Image
    - GW Education Program
      - Build Green Centre
        - Reduce Operating Costs
          - Process Green Waste
            - depends
            - hurts
            - helps

- makes
- depends
- helps
Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

2. How does building a green centre and not building a dump affect the top level goals?
Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

2. How does building a green centre and not building a dump affect the top level goals?

Use Qualitative Evaluation Labels with Forward Analysis and Backward Analysis

<table>
<thead>
<tr>
<th>Denied</th>
<th>Satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partially Denied</td>
<td>Partially Satisfied</td>
</tr>
<tr>
<td>Conflict</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?
Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?
Question: Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

Answer: Yes, by build a green centre and a small dump.
Waste Management Example

How does building a green centre and not building a dump affect the top level goals?
Waste Management Example

How does building a green centre and not building a dump affect the top level goals?
Question: How does building a green centre and not building a dump affect the top level goals?

Answer: It satisfies (or partially satisfies) the top goals, except Reduce Operating Costs.
Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

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Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

2. How does building a green centre and not building a dump affect the top level goals?

3. How do changes in Environmental Concern affect the city's root-level goals over time?

4. Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

5. Does the order of these developments (Process Green Waste and Use New Dump) matter?

See paper for additional questions…
Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

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See paper for additional questions…
Contributions

• Understand the impacts of dynamically changing intentions on decision making

• Enrich goal models intentions with dynamically changing evaluation
Outline

• Motivating Example - City Waste Management

• **Modeling Dynamic Intentions**

• Analysis Techniques with Dynamic Intentions
  - Simulation
  - CSP and CSP with Constraints

• Tooling and Validation

• Conclusion and Future Directions
Modeling Dynamic Intentions

- City
  - Manage City Waste
    - Comply with Standards
    - Build Large Dump
    - Purchase Land
  - Use Current Dump
    - or
    - Use New Dump
  - Update Truck Route
  - Upgrade Trucks

- Space in Dump
  - and
  - Process Green Waste
    - hurts
    - helps
  - Build Green Centre
  - GW Education Program

- Positive City Image
  - depends
  - Environmental Concern
    - makes
    - Willingness to Separate Waste
    - makes
    - Enjoy City

- Citizen
  - Quality of Waste Separation

- Manage City Waste
  - depends
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  - Have Workers Union Contract
  - Reduce Operating Costs
    - or
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  - Build Green Centre
  - GW Education Program

- Actor
  - Goal
  - Task
  - Soft Goal
  - Resource

- Decomposition
  - or
  - Dependency
  - makes
  - Contribution
Modeling Dynamic Intentions

Stochastic (R)

Patterns:

Examples:

Environmental Concern
Modeling Dynamic Intentions

Elementary Functions

Stochastic (R):

- Increase (I):
  - ✓...
  - ✗...

- Decrease (D):
  - ✓...
  - ✗...

Constant (C):

- ✓...
- ✓ or ✗...

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Modeling Dynamic Intentions

Denied-Satisfied (DS)

Patterns:

Examples:
Modeling Dynamic Intentions

Denied-Satisfied (DS)

Patterns:

Epoch Boundary

Examples:

- Build Small Dump
- Build Large Dump
- Build Green Centre
Modeling Dynamic Intentions

Monotonic Negative (MN)

Patterns:

Examples:
## Common Compound Functions

<table>
<thead>
<tr>
<th>Denied-Satisfied (DS)</th>
<th>the satisfaction evaluation remains <em>Denied</em> until $t_i$ and then remains <em>Satisfied</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Monotonic Negative (MN)</td>
<td>changes in satisfaction evaluation become “less true” to a $maxValue$ at $t_i$ and then remains constant at $constantValue$</td>
</tr>
<tr>
<td>Compound Functions</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Satisfied-Denied (SD)</td>
<td>the satisfaction evaluation remains <em>Satisfied</em> until $t_i$ and then remains <em>Denied</em></td>
</tr>
<tr>
<td>Denied-Satisfied (DS)</td>
<td>the satisfaction evaluation remains <em>Denied</em> until $t_i$ and then remains <em>Satisfied</em></td>
</tr>
<tr>
<td>Stochastic-Constant (RC)</td>
<td>changes in satisfaction evaluation are stochastic or random until $t_i$ and then remains constant at $constantValue$</td>
</tr>
<tr>
<td>Constant-Stochastic (CR)</td>
<td>the satisfaction evaluation remains constant at $constantValue$ until $t_i$ and then changes in evaluation are stochastic or random</td>
</tr>
<tr>
<td>Monotonic Positive (MP)</td>
<td>changes in satisfaction evaluation become “more true” to a $maxValue$ at $t_i$ and then remains constant at $constantValue$</td>
</tr>
<tr>
<td>Monotonic Negative (MN)</td>
<td>changes in satisfaction evaluation become “less true” to a $maxValue$ at $t_i$ and then remains constant at $constantValue$</td>
</tr>
</tbody>
</table>
User Defined (UD)
Outline

• Motivating Example - City Waste Management

• Modeling Dynamic Intentions

• **Analysis Techniques with Dynamic Intentions**
  - Simulation
  - CSP and CSP with Constraints

• Tooling and Validation

• Conclusion and Future Directions
Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

2. How does building a green centre and not building a dump affect the top level goals?

3. How do changes in Environmental Concern affect the city's root-level goals over time?

4. Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

5. Does the order of these developments (Process Green Waste and Use New Dump) matter?
Strategies

(Strategy 1) create a **random path** given initial states in the model

(Strategy 2) create a path given **desired properties** of the **intermediate state** (with optional properties over the initial or final state)

(Strategy 3) create a path which is **different than the previously seen path** over the same constraints
Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

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Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

2. How does building a green centre and not building a dump affect the top level goals?

3. How do changes in *Environmental Concern* affect the city's root-level goals over time?

4. Which possible scenarios in *Manage City Waste* even if *Space in Dump* becomes denied in the future?

5. Does the order of these developments (*Process Green Waste* and *Use New Dump*) matter?

Strategy 1: create a random path given **initial states** in the model - Leaf Simulation -
How do changes in Environmental Concern affect the city's root-level goals over time?
Leaf Simulation (Initial States)

How do changes in Environmental Concern affect the city's root-level goals over time?
Leaf Simulation (Initial States)

How do changes in Environmental Concern affect the city's root-level goals over time?
Question: How do changes in Environmental Concern affect the city's root-level goals over time?

Answer: Affects Reduced Operating Cost and Enjoy City. Having a GW Education Program mitigates the effect of denied environmental concern.
Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

2. How does building a green centre and not building a dump affect the top level goals?

3. How do changes in Environmental Concern affect the city's root-level goals over time?

4. Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

5. Does the order of these developments (Process Green Waste and Use New Dump) matter?
1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

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4. Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

5. Does the order of these developments (Process Green Waste and Use New Dump) matter?

Strategy 2: create a path given desired properties of the intermediate state (with optional properties over the initial or final state) - CSP Analysis -
Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?
CSP Analysis (Intermediate/Final)

Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

MCW_0 = 3
Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

\[
\text{SiD}_2 \geq \text{SiD}_3 \\
\text{If EpochBound } \leq 3 \text{ Then SiD}_3 = 0
\]

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Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

\[ \text{SiD}_2 \geq \text{SiD}_3 \]

If \( \text{EpochBound} \leq 3 \) Then \( \text{SiD}_3 = 0 \)

\( \text{EpochBound} \neq 8 \)
Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

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If \( \text{EpochBound} \leq 3 \) Then \( \text{SiD}_3 = 0 \)

\( \text{EpochBound} \neq 8 \)

**Strategy 3:** create a path which is different than the previously seen path over the same constraints

- CSP History -
Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?
Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?
Question: Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

Answer: Build Large Dump must be satisfied prior to Space in Dump becoming denied.

Note: Build Small Dump also suffices (paths not shown).
1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

2. How does building a green centre and not building a dump affect the top level goals?

3. How do changes in Environmental Concern affect the city's root-level goals over time?

4. Which possible scenarios always satisfy Manage City Waste even if Space in Dump becomes denied in the future?

5. Does the order of these developments (Process Green Waste and Use New Dump) matter?
Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

2. How does building a green centre and not building a dump affect the top level goals?

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5. Does the order of these developments (Process Green Waste and Use New Dump) matter?

Strategy 2: create a path given desired properties of the intermediate state (with optional properties over the initial or final state)

- CSP Analysis (with Queries) -
CSP Analysis (with Queries)

Does the order of these developments (Process Green Waste and Use New Dump) matter?

A: Process Green Waste
B: Use New Dump

History Log

Step 1: CSP A<B
Step 2: CSP B<A
Step 3: CSP A=B

R: Stochastic, C: Constant, UD: User Defined
DS: Denied-Satisfied, MN: Monotonic Negative

Denied × Satisfied ✓
Partially Denied × Partially Satisfied ✓
Conflict ≥? Unknown
CSP Analysis (with Queries)

Does the order of these developments (Process Green Waste and Use New Dump) matter?

A: Process Green Waste
B: Use New Dump

R: Stochastic, C: Constant, UD: User Defined
DS: Denied-Satisfied, MN: Monotonic Negative
Question: Does the order of these developments (Process Green Waste and Use New Dump) matter?

Answer: No, given space in current dump.
Waste Management Example

1. Is it possible to satisfy Manage City Waste and partially satisfy Enjoy City? and how?

2. How does building a green centre and not building a dump affect the top level goals?

3. How do changes in *Environmental Concern* affect the city's root-level goals over time?

4. Which possible scenarios always satisfy *Manage City Waste* even if *Space in Dump* becomes denied in the future?

5. Does the order of these developments (*Process Green Waste* and *Use New Dump*) matter?

See paper for additional questions…
1. Build Green Centre and Build Small Dump is a possible scenario.

2. Building only Green Centre satisfies (or partially satisfies) the top goals, except Reduce Operating Costs.

3. Environmental Concern affects Reduced Operating Cost and Enjoy City over time. Having a GW Education Program mitigates the effect of denied Environmental Concern.

4. Build Large Dump (or Build Small Dump) must be satisfied prior to Space in Dump becoming denied.

5. Order of Process Green Waste and Use New Dump doesn’t matter, given Space in Dump is not denied.
Waste Management Review

Goal: Evaluate waste management infrastructure

Intentions: Wants to be green and satisfy customer

Options: Build Green Centre
Build Landfill / Dump (large, small)

Solution (Standard): Build Green Centre

Solution (with Dynamics): Build Small Dump then Build Green Centre
Outline

• Motivating Example - City Waste Management
• Modeling Dynamic Intentions
• Analysis Techniques with Dynamic Intentions
  - Simulation
  - CSP and CSP with Constraints
• Tooling and Validation
• Conclusion and Future Directions
Tooling: GrowingLeaf

http://www.cs.toronto.edu/~amgrubb/growing-leaf
Examples and Case Studies

- City transportation planning
- Network maintenance
- Software supply chains
- Technical debt
- Compliance
- Sustainability

Further case studies are ongoing....
Scalability

• How does the length of the generated path affect the computation time in Strategy 1 and 2?

• How does the number of intentions in a model affect the computation time in Strategy 2?

• How does the number of previous paths used affect the computation time in Strategy 3?

Details in the paper…
Scalability: Model Size

Results of changing the model size for CSP Analysis.
Related Work

Dynamic Changing Intentions & Analysis
Related Work

![Diagram]

Analysis
Techniques &
Encoding

Dynamic
Changing
Intentions &
Analysis
Related Work

- Analysis Techniques & Encoding
- Dynamic Changing Intentions & Analysis
- Changing Goals
Related Work

- Changing Goals
- Dynamic Changing Intentions & Analysis
- Analysis Techniques & Encoding
- Goals Outside Early-RE
Related Work

- Changing Goals
- Analysis Techniques & Encoding
- Dynamic Changing Intentions & Analysis
- Goals Outside Early-RE
- Simulation of Agents
Related Work

- Analysis Techniques & Encoding
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- Requirements Evolution
Related Work

Analysis Techniques & Encoding

Changing Goals

Dynamic Changing Intentions & Analysis

Goals Outside Early-RE

Simulation of Agents

Requirements Evolution

**Where do Goals Come from: the Underlying Principles of Goal-Oriented Requirements Engineering**

Gil Regen, Alwin Wegmann
Ecole Polytechnique Federale de Lausanne (EPFL), School of Communication and Computer Science CH-1015 Lausanne, Switzerland
(gil.regen, alwin.wegmann)@epfl.ch

**Abstract**

Goals are a widely used concept in requirements engineering. Several kinds of goals, such as achievement, maintenance and soft goals, have been defined in these methods. These methods also define heuristics for the identification of organizational goals that derive the requirements process. In this paper we propose a set of principles that explain the nature of goal-oriented behavior. These principles are based on regulatory mechanisms as defined in General Systems Thinking and Cybernetics. We use these principles to analyze the existing definitions of these different kinds of goals and to propose more precise definitions. We establish the similarities and differences between these kinds of goals, and propose extensions for goal-identification heuristics.

1 Introduction

The emergence of requirements engineering as a separate discipline from computer science and systems engineering in the early 1990s coincided with the development of methods for defining requirements based on goals, as called Goal-Oriented Requirement Engineering (GORE) methods [19]. Goals are now considered as a core concept in RE [9].

Requirements engineering research has focused on goals as a way of providing the rationale (why) for an envisioned system [19]. This helps in identifying, organizing, and managing requirements as well as in driving the requirements elicitation process [1].

Several GORE methods have been defined that give more attention to one or more of these aspects e.g. CREW (11), GRAM (1), ORIE (14), P* (28), KAOS (29). GORE research has focused on the development of methods. Little research has been done on the underlying principles of GORE. As a result there is room for improvement in the understanding of the similarities and differences between the many kinds of goals that have been proposed in GORE methods, e.g. achievement, maintenance and soft goals. For example, achievement goals are said to comply with maintenance goals (1) but this relationship has not been made more precise. The same applies to the relationship between maintenance and soft goals.

In this paper we propose a set of underlying principles for goal-oriented behavior in organizations. These principles are based on regulatory mechanisms as defined in General Systems Thinking (GST) and Cybernetics (1). Understanding these principles helps in analyzing how goals affect organizations in changing environments and changing goals.

2 The Use of Goals in GORE methods

GORE methods take their root in Artificial Intelligence problem solving (14). The reason for focusing on goals, found in the GOOR literature (1, 3, 14), is the higher level of requirements afford by goals as a way of providing the rationale (why) for an envisioned system.
Related Work

Analysis Techniques & Encoding

Changing Goals

Dynamic Changing Intentions & Analysis

Goals Outside Early-RE

Simulation of Agents

Requirements Evolution

Where do Goals Come from: the Underlying Principles of Goal-Oriented Requirements Engineering

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Abstract

Goal is a widely used concept in requirements engineering methods. Several kinds of goals, such as achievement, maintenance and self goals, have been defined in these methods. These methods also define heuristics for the identification of organizational goals that drive the requirements process. In this paper we propose a set of principles that explain the nature of goal-oriented behavior. These principles are based on regulatory mechanisms as defined in General Systems Thinking and Cybernetics. We use these principles to analyze the existing definitions of these different kinds of goals and to propose more precise definitions. We establish the commonalities and differences between these kinds of goals, and propose extensions for goal identification heuristics.

1 Introduction

The emergence of requirements engineering as a separate discipline from computer science and systems engineering in the early 1980s coincided with the development of methods for defining requirements based on goals, also called Goal-Oriented Requirements Engineering (GORE) methods [19].

Requirements engineering research has focused on goals as a way of providing the rationale (why) for system design decisions. This work has led to several different goal-oriented frameworks. The focus of this paper is on the LightBuch Goal-Oriented Framework [17] and the GORE 2000 framework [10]. These frameworks are based on different methodologies and provide a structured approach to the identification and analysis of goals.

In this paper, we examine the role of goals in the requirements process and present a new approach for the analysis of goals. We start by defining the concept of goal and then propose a set of principles that explain the nature of goal-oriented behavior.

2 The Use of Goals in GORE methods

GORE methods take their inspiration from AI research into problem solving [18]. The reasons for focusing on goals, found in the GORE literature [1, 8, 10], are the higher level of requirements influenced by goals as well as the importance of reasoning about goals to achieve this level of abstraction.

3 Related Work

Related Work

Changing Goals

Dynamic Changing Intentions & Analysis

Goals Outside Early-RE

Simulation of Agents

Requirements Evolution

Analysis Techniques & Encoding

Run-time Goal Models

Abstract—Goal models support stakeholder requirements for a system, but they also enable a tight coupling of stakeholders and developers. This paper develops the use of run-time goal models as a key technique to support reasoning about requirements during development. The use of run-time goal models is based on the observation that the information in requirement models changes over time. We define a class of run-time goal models that are used to represent the current state of requirements and their evolution. Run-time goal models are used to track the evolution of requirements and to support the management of requirements during development.

Run-time Goal Models

As a method for tracking the evolution of requirements, goal models have been shown to be valuable for supporting the development process. However, run-time goal models have not been widely used in practice, as they are difficult to maintain and provide little insight into the evolution of requirements.

In this paper, we present a method for developing run-time goal models that is based on a set of techniques for tracking the evolution of requirements. We use these techniques to develop a set of run-time goal models that are used to track the evolution of requirements and to support the management of requirements during development.

We demonstrate the effectiveness of our approach by comparing it with a previous approach to track the evolution of requirements. Our approach is shown to be more effective in supporting the development process, as it provides a better understanding of the evolution of requirements and allows for better decision making.

Acknowledgements

We would like to thank the anonymous reviewers for their comments on an earlier version of this paper. We also thank the participants of the Requirements Engineering Workshops for their feedback on this work.
Summary

Motivating Example

Goal: Evaluate waste management infrastructure
Intentions: Wants to be green and satisfy customer
Options: Build Green Centre
Build Landfill / Dump (large, small)
Approach: Choose correct alternative(s)
using goal modeling.

Modeling Dynamic Intentions

Elementary Functions

Stochastic (R):

Constant (C):

Increase (I):

Decrease (D):

Strategies

(Strategy 1) create a random path given initial states
in the model

(Strategy 2) create a path given desired properties
of the intermediate state (with optional properties
over the initial or final state)

(Strategy 3) create a path which is different than the
previously seen path over the same constraints

Leaf Simulation (Initial States)
Future Work

• Evaluate effectiveness

• External industrial case study

• Add “wall clock time” to analysis

• Optimize CSP encoding

• Formally specify our extension
Questions?
Looking into the Crystal Ball: Requirements Evolution over Time

Contributions:

- Understand the impacts of dynamically changing intentions on decision making
- Enrich goal models intentions with dynamically changing evaluation

Alicia M. Grubb
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