A Service-Oriented Infrastructure for Adaptive Systems Based on Specification-Carrying Code

Giovanna Di Marzo Serugendo
dimarzo@dcs.bbk.ac.uk

Birkbeck College, University of London
http://www.dcs.bbk.ac.uk/~dimarzo

Outline

- Framework
- « Specification-Carrying Code » (SCC)
- Applications
  - Unanticipated code evolution
  - Autonomic Computing
  - Dynamically Resilient Systems

Framework (1)

- Applications Domains
  - Wireless / Ad hoc Networks
  - Grid
  - Ambient Intelligence
  - Autonomic Computing
  - Large Scale Security Systems

Framework (2)

- Characteristics
  - Large scale open distributed systems
  - Autonomous and heterogeneous entities
  - Decentralised control
  - Large number of components

Framework (3)

- Characteristics
  - Dynamic and uncertain environment
  - Need for adaptability
  - Social dimension
    - Interactions, discovery, negotiations, transactions
  - Self-organisation (adaptability/robustness)
  - Emergent Phenomena

Issues

- Interactions with unknown entities (semantics)
  - Understanding
  - Interoperability
- Management of uncertainty (social)
  - Malicious entities (exhibit desirable characteristics, but …)
  - Good faith entities (fail because: software error, lack of toner, paper jam, …)
- Design of systems with decentralised control
  - How to realise self-organisation?
  - How to realise self-managing systems?
- Control of emergent phenomena
  - Desired or undesired, but with a causal effect on system

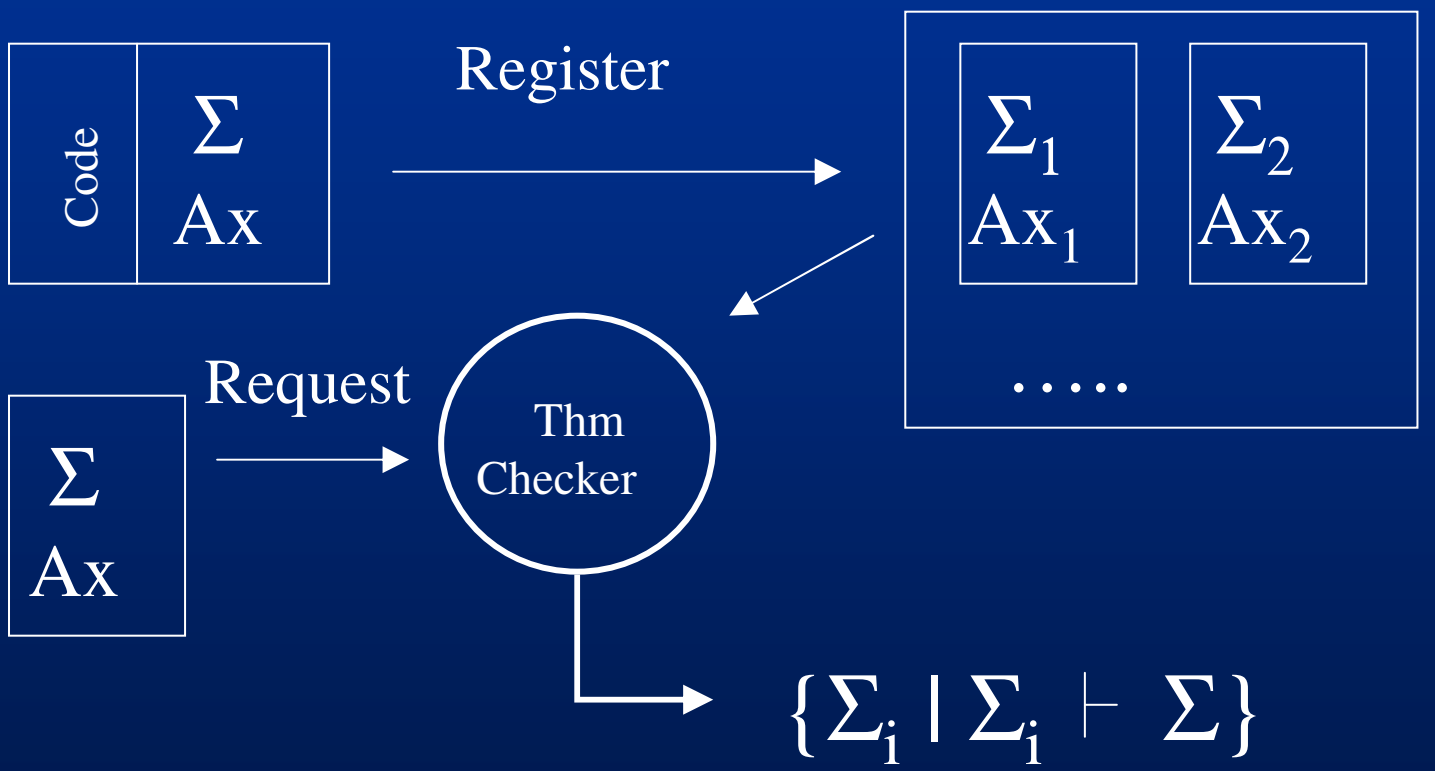
Specification-Carrying Code

- Idea: *communication is based on a formal specification of the behaviour of a peer entity*
  - Software « carries » a formal description of its own functional behaviour
  - Communication occurs without API
  - Formal specification defines the semantics of the behaviour

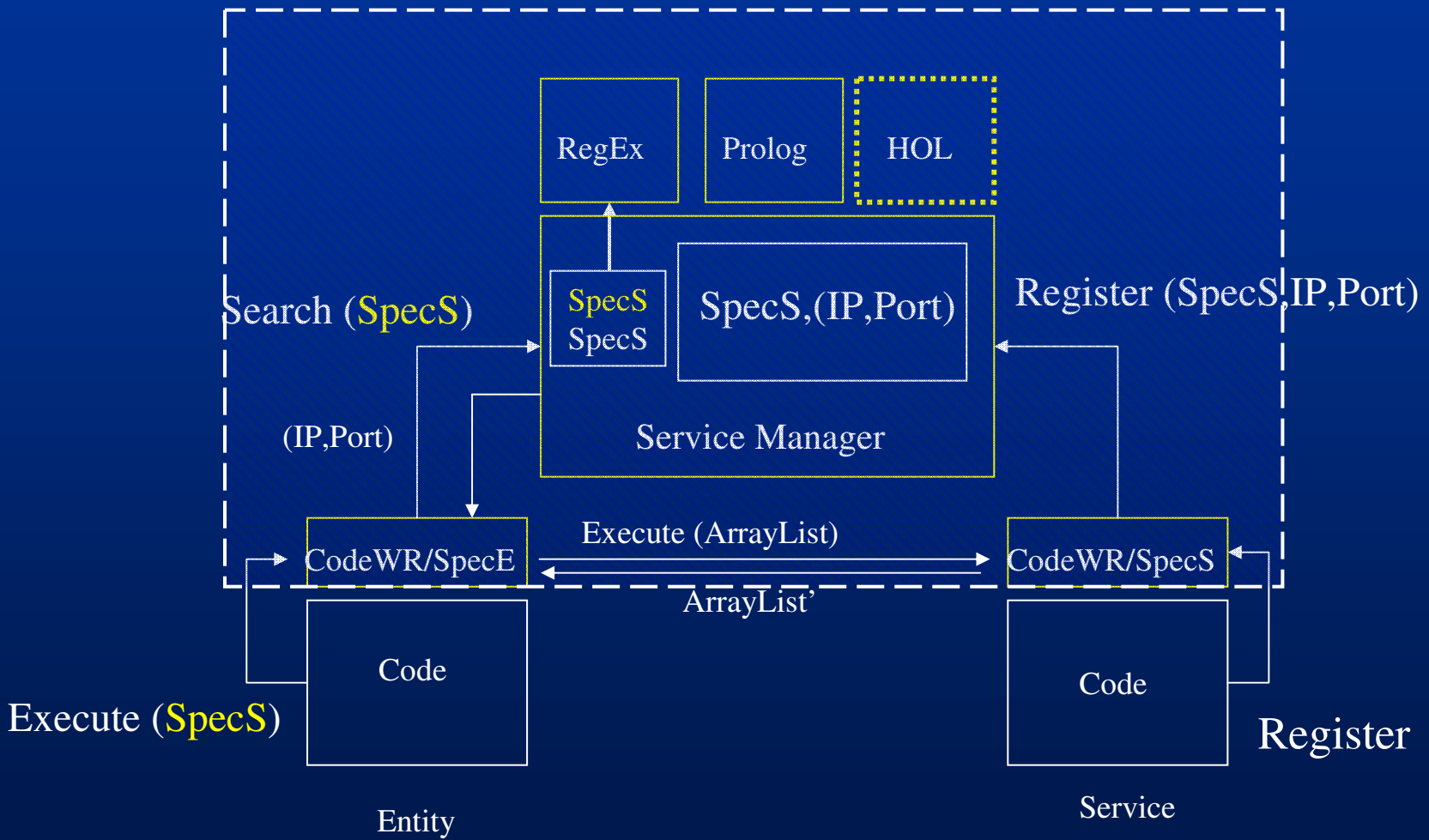
SCC - Principle

- Scenario
  - Publication of specifications
    - Services requested / Services proposed
  - Specification matching
    - Proposed service matches requested service
  - Service realised in an anonymous / asynchronous / non-deterministic manner
- Interest
  - Minimum basis for communication
    - Specification language (for expressing concepts)
  - Interaction with new software / with unknown software
  - No central control (self-assembly)

SCC - Principle



SCC - Architecture



SCC – Prolog

- Registration

```
<specs>
  <description active="true">
    <content> Reverse List Service
    </content>
  </description>
  <prolog active="true">
    <content>
      append([],L,L).
      append([H|T],L2,[H|L3]):-
          append(T,L2,L3).

      rev([],[]).
      rev([H|T],R) :-  rev(T,RevT),
          append(RevT,[H],R).
    </content>
  </prolog>
</specs>
```

- Request

```
<specs>
  <description active="true">
      <content> ReverseList Request </content>
  </description>
  <prolog active="true">
    <content>
      rev([],[]), rev([A|B],R), rev(B,RevB),
      append(RevB,[A],R), rev(R,[A|B]).
    </content>
  </prolog>
</specs>
```

SCC – Java (no API!)

- Registration

```
public class ReverseList extends Service {

public class static void main(String[] args)
      //register reverse list specification
      new ReverseList().register(« localhost »,
       « specService.xml » );
     }

public ArrayList execute(ArrayList list) {
      Collections.reverseList(list);
      return list;
     }
}
```

- Request

```
public class UseReverseList extends Entity {

private void askForReverseList() {
     // request a reverse list service
      result = Entity.execute(SM_ADDRESS,
       « specRequest.xml », parameters);
     }
}
```

SCC – Alternatives

- Specification
  - ✓ Keywords
  - ✓ Regular Expressions (syntactic)
  - ✓ Prolog (SWIProlog)
  - – HOL (Isabelle Thm Prover – meta-ontology)
  - – Jena (Logic + ontology)
  - – Common Simple Logic
- Architecture
  - ✓ Publication of specifications (asynchronous / anonymous / non-deterministic)
  - – Direct exchange of specifications (interaction decisions)
- Service Discovery
  - – JXTA protocols
  - – Géo-positioning
- Information contained in the specification
  - – Functional
  - – Non-functional, security, reputation, positioning, etc,

SCC vs PCC vs Trust

- SCC
  - Code is decoupled from specification
  - No guarantee that the code satisfies the specification
  - It is the same with APIs!
- Proof Carrying Code (PCC) [Necula04]
  - Code « carries » the proof that it is correct
    - Low level (no infinite loop, no division by zero)
    - Not at the functional level
    - No specification
  - What happens if the code/proof are malicious?
  - What happens if the code/proof are in good faith, but the code fails?
- Trust
  - Adaptation mechanism based on experience and observation

SCC – Interest and Issues

- No central control
  - Spontaneous registrations and requests
- Minimum basis for communication
  - Specification language (for expressing concepts)
- Interaction/Interoperability with unknown (or heterogeneous) peers
  - No common design / No common API
- Self-assembly
- Seamless Integration of new entities

SCC – Interest and Issues

- Robustness
- Service Composition
- Adaptability
  - Feedback available among services through specifications (modifications)
- Services can be:
  - Computation / data provider / manager
- Issues
  - Specification Language
    - Expressivity vs run-time processing
    - Matching tool

Applications

- Unanticipated Evolution of Code
- Autonomic Computing
- Dynamically Resilient Systems

Unanticipated Evolution of Code

- Code changes during its execution (without stopping the application)
- Non anticipated evolution
  - Non anticipated by the programmer
- Distribution on the fly
- Experiments
  - Web Server
    - 160 different versions of the server, with only 4 stops
  - Tic-Tac-toe for Open Days
    - Changes done to the application *during the play*

Autonomic Computing

- Self-Configuration (installation, configuration, integration)

  "*Automated configuration of components and systems follow high-level policies. Rest of System adjusts automatically and seamlessly [Kephart03]*"

  - SCC expresses high-level configuration policies
    - High-level requests (goals) from human admin (installation needs)
    - High-level requests for configuration policies (Grid distribution)
    - Local-level: components express individual installation needs (CPU, memory, etc.)

  - Unanticipated dynamic run-time evolution of code
    - Seamless integration of new components
    - Distribution of application on-the-fly

Autonomic Computing

- Self-Optimisation (parameters)

  "*Components and systems continually seek opportunities to improve their own performance and efficiency [Kephart03*]"

  - SCC expresses optimisation policies
    - Parameters description
    - Permanent optimisation of parameters depending on the context
  - At each request
    - SCC Middleware seeks optimised service (most recent, most efficient, etc.)

Autonomic Computing

- Self-Healing (error detection, diagnostic, repair)

  "*System automatically detects, diagnoses, and repairs localized software and hardware problems [Kephart03]"*

  - Generation of correct code from SCC
  - Replace error code with code having matching specification
  - Checking of code against specification

Autonomic Computing

- Self-protection (detection and response to attacks)

  "System automatically defends against malicious attacks or cascading failures. It uses early warning to anticipate and prevent systemwide failures [Kephart03]"

  - SCC expresses high-level security policies
    - Conditions regulating services delivery
    - Signatures of attacks / Response schema
  - Self-regulating schema
    - Trust and reputation information

Autonomic Computing

- SCC expresses
  - Functional Behaviour
  - Non-Functional Aspects
    - Policies
    - Trust
    - Quality of Service
  - Execution Flow

Dynamically Resilient Systems

- Resilience
  - Capacity to resist to impairments
- Dynamic resilience
  - Dynamic adaptation to changing environment
  - Maintain an acceptable level of quality of service
- Predictable dynamic resilience
  - Dynamic resilience predictable at design time

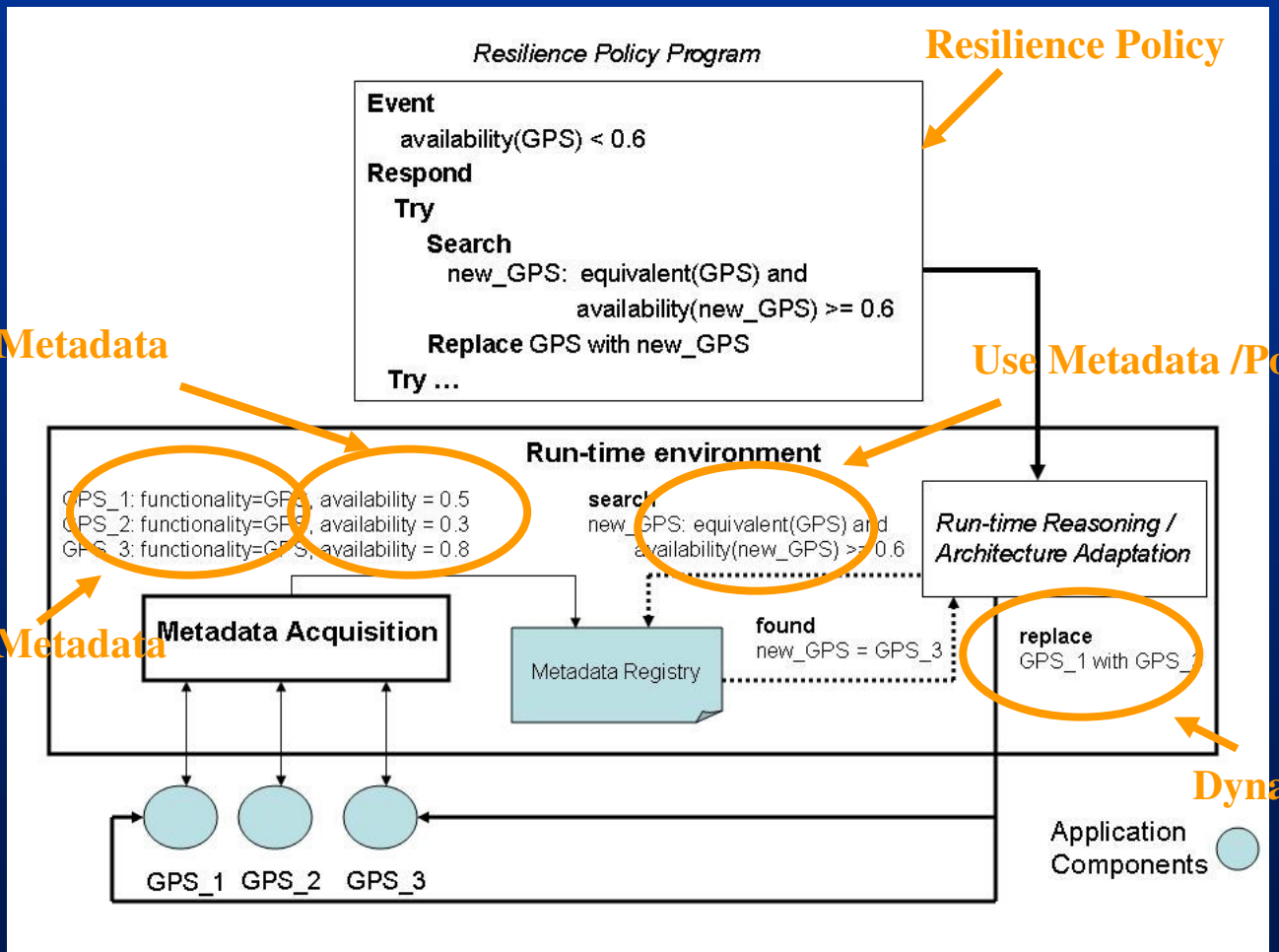
Dynamically Resilient Systems

- Metadata
  - Functional
  - Non-functional (QoS): permanently updated
  - Resilience metadata: permanently updated
- Resilience mechanism (design time)
  - "Design pattern for resilience"
- Resilience policies (run-time)
  - Policy used at run-time to enforce resilience
  - Formal language
- Reasoning and adaptation services
  - Run-time environment
  - Enforce resilience policies (matching)
  - Use metadata information
  - Adapt service (change)

Dynamically Resilient Systems

- GPS Example
  - System with 3 GPS
  - Resilience mechanism
    - "Switch to GPS with higher availability if current GPS has availability lower than 0.6"
- Metadata
  - Functional: "Functionality = GPS"
  - Non-functional resilient: "Availability"

Dynamically Resilient Systems



Other applications

- Grid computing
  - Resource allocations
  - Load balancing
- Digital Right Managements
  - "Who is allowed to view/modify/use digital document ?"
  - Policy specifies "who/when/what"
  - Dynamic change of policy at run-time
    - Modification of rights on the fly
- E-government
  - Law requirements → Policies
  - Change of law → Change of policy + No-change of code

Summary

- Goal
  - Design self-* systems with predictable behaviour
- Idea
  - Use of formal specifications / metadata at run-time:
    - Functional behaviour
    - Non-functional constraints
    - Rules/Policies/etc.
- Realisation
  - Run-time service-oriented middleware
    - Enforcing functional behaviour / constraints / policies
    - Dynamic changes of components
    - On the basis of formal specifications and metadata at run-time

Additional Activities

- IEEE SASO Conference
  - http://projects.csail.mit.edu/saso2007/
- Agentlink Technical Forum on Self-Organisation
  - http://www.agentlink.org/activities/al3-tf
- IEEE ETTC Organic Computing Task Force
  - http://www.neuroinformatik.ruhr-uni-bochum.de/PEOPLE/igel/oc.html
- ACM Transactions on Autonomous Adaptive Systems
  - Inaugural issue: September 2006
  - http://www.acm.org/pubs/taas

Papers

- G. Di Marzo Serugendo, J. Fitzgerald, A. Romanovsky, N. Guelfi. *"A Metadata-Based Architectural Model for Dynamically Resilient Systems"*, ACM Symposium on Applied Computing (SAC'07) - Dependable and Adaptive Distributed Systems (DADS), 2007.

- G. Di Marzo Serugendo, M.-P. Gleizes, A. Karageorgos. *"Self-organisation and emergence in MAS: an overview"*, Informatica 30(1): 45-54, Slovene Society Informatika, Ljubljana, Slovenia, 2006.

- M. Oriol, G. Di Marzo Serugendo, "*A Disconnected Service Architecture for Unanticipated Run-time Evolution of Code*", IEE Proceedings-Software, Special Issue on Unanticipated Software Evolution, Susan Eisenbach (Ed), 2004.

- M. Oriol: "*An Approach to the Dynamic Evolution of Software Systems*". PhD in Information Sysems. Faculty of Economic and Social Sciences, University of Geneva, 2004.

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- Jeffrey O. Kephart, David M. Chess, *"The Vision of Autonomic Computing"*. IEEE Computer 36(1): 41-50, 2003