# Executable Modeling of Deployment Decisions for Resource-Aware Distributed Applications

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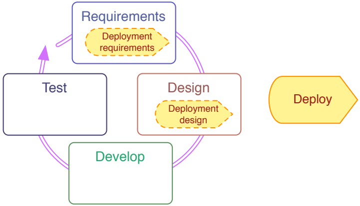
# Overview

## Deployment

Various activities that place a software application on computing devices




- Problem:
  Performance during the operational phase is below expectations
- Why?
  Characteristics of the deployment infrastructures influence performance
- Possible actions to improve performance:
  Redeploy, redesign applications
- Hypothesis:
  It is advantageous to include deployment decisions in the design phase

# Overview

## Research Goal

*Develop a methodology to express and compare different deployment decisions for resource-aware distributed applications during the design phase.*

Requirements:

- Concurrent, distributed and object-oriented framework
- Model based approach
- Formality

Integrate in a modeling language:

- Deployment architectures
- Deployment decisions

In order to:

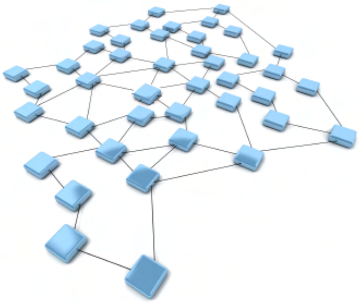
- Estimate and quantify QoS
- Compare deployment architectures

# Overall Contributions of this Thesis

- Starting point is Core ABS:
  - Executable and object-oriented modeling language with a formal semantics and a Java-like syntax
  - Clear and simple concurrency model (using COGs) with synchronous and asynchronous communication
- Formally defined extensions of Core ABS:
  - Explicit and implicit modeling of dense time (Real-Time ABS)
  - User-defined cost annotations
  - Deadlines to method calls
  - Modeling of deployment architectures
  - Resource management: load-balancing and user-defined schedulers
- Validation of methodology and formalization
  - Modeling examples and case studies
  - Analysis results: Simulations
- Publications:
  - This thesis collects four paper (two journal papers, two conference papers)
  - Eight additional papers (not included in this thesis)

# Outline

- Motivating example
- Research goal and research questions
- Summary and future work



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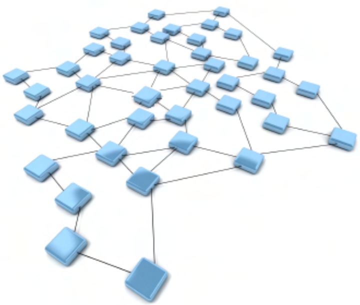
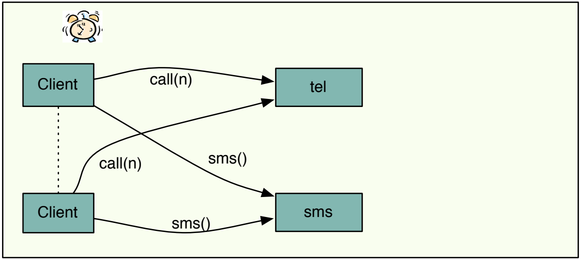


# Example definition: Phone Services



# Example: Phone Services - Real-Time ABS

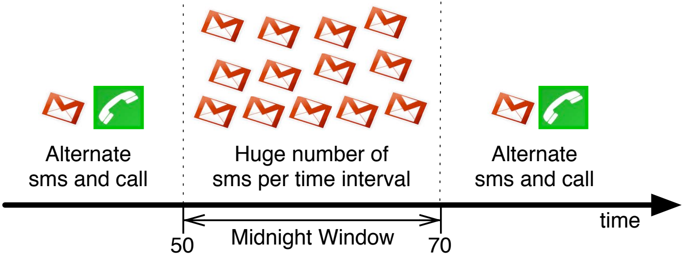
## Telephone Service

```
interface TelephoneService {
    Unit call(Int calltime);
}
class TelephoneServer implements TelephoneServer {
  Int callcount = 0;
  Unit call(Int calltime){
    while (calltime > 0) { [Cost: 1] calltime = calltime − 1;
                            await duration(1, 1); }
    callcount = callcount + 1;
  }
}
```

## SMS Service

```
interface SMSService {
    Unit sendSMS();
}
class SMSServer implements SMSServer {
  Int smscount = 0;
  Unit sendSMS() {[Cost: 1] smscount = smscount + 1;}
}
```

# Example: Phone Services
# Client Behavior on New Year's Eve




Simulate the operation of the system outside standard usage.
Client can flood the system and create congestion

# Example 2: Phone Services - Client Handsets

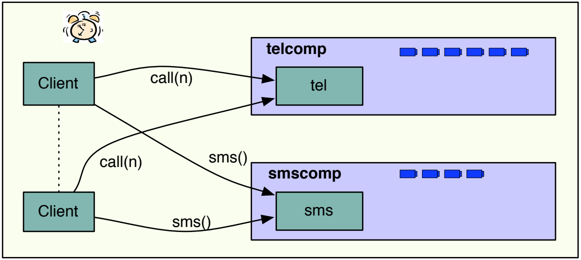
```
class Handset (Int cyclelength,TelephoneService ts,SMSService smss){
  Bool call=false;

  Unit normalBehavior(){
      if (timeValue(now()) > 50 && timeValue(now()) < 70) {
          this!midnightWindow();
      } else {
          if (call) { ts.call(1); } else {smss!sendSMS();};
          call = ~call; await duration(cyclelength,cyclelength);
          this!normalBehavior(); }
  }

  Unit midnightWindow(){ Time t=now(); Int i=0;
      if (timeValue(now()) >= 70) {
          this!normalBehavior();
      } else { Int i = 0;
      while (i < 10) {
        smss!sendSMS(); i = i + 1;
      }
      await duration(1,1); this!midnightWindow();
    }
  }

  Unit run(){this!normalBehavior();}
}
```

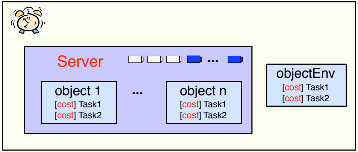
# Example: Phone Services - Deployment Modeling




How a functional model will perform in
a given deployment architecture

# Deployment Components (new constructor)

Deployment component acts as an execution location

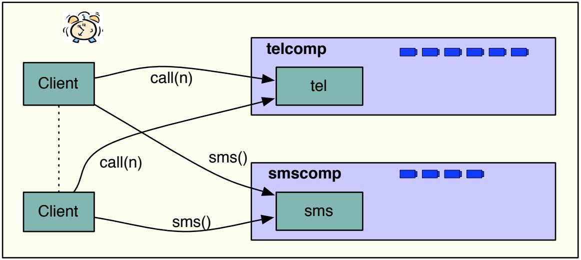



- **Locations** for concurrent objects in ABS
- Each deployment component has a given resource capacity

- Objects execute in the context of a deployment component
- The *resources are shared* between the component's objects
- Object execution *uses* resources in a deployment component (via `Cost` annotation)

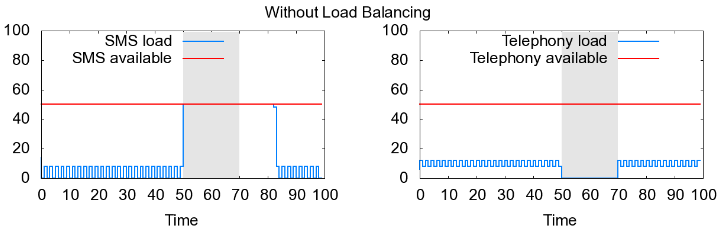
- *How* resources are assigned and consumed depends on the kind of resource
- Phone services example: computing capacity per time interval

# Example: Phone Services - Deployment Modeling




```
{// Main block:
    DC smscomp = new cog DeploymentComponent("smscomp", CPU(50));
    DC telcomp = new cog DeploymentComponent("telcomp", CPU(50));
    [DC: smscomp] SMSService sms = new cog SMSServer();
    [DC: telcomp] TelephoneService tel = new cog TelephoneServer();
    c = new cog Handset(1,tel,sms); ... // Clients handsets
}
```

# Example 1: Phone Services - Simulation Results

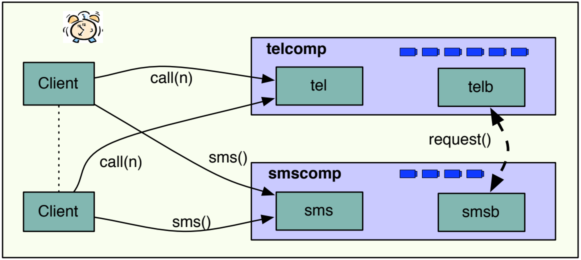



Can the performance of the phone service model be improved?

Can the computing resources of a deployment architecture be better used?

# Example: Phone Services - Resource Management

Resource management using a simple load balancing strategy




**Example strategy:** Reallocate $1/3\times$total resources upon request from partner

# Example: Phone Services
# A Simple Load Balancing Strategy

```
class Balancer implements Balancer {
  Balancer partner = null;

  Unit run() {
    await partner != null;
    while (True) {
      await duration(1, 1);
      Int tl = thisDC().total(); Int ld = thisDC().load(1);
      if (ld > 90) {
        Fut<Unit> r = partner!requestdc(thisDC()); await r?;
      }
    }
  }

  Unit requestdc(DC comp) {
    Int tl = thisDC().total(); Int ld = thisDC().load(1);
    if (ld < 50) {
      thisDC()!transfer(comp, capacity(tl) / 3);
    }
  }
  Unit setPartner(Balancer p) { partner = p; }
}
```

# Example: Phone Services
# Deployment Scenario with Balancers

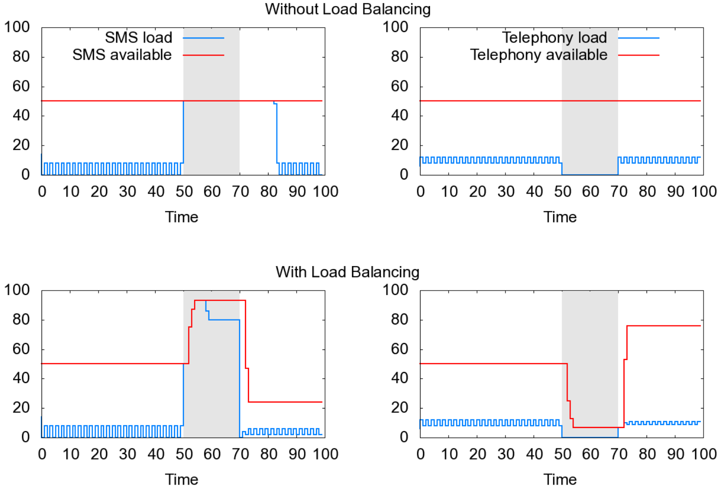
Main block of the Real-Time ABS model with load balancing

```
{ // Main block
  DC smscomp = new cog DeploymentComponent("smscomp", CPU(20));
  DC telcomp = new cog DeploymentComponent("telcomp", CPU(20));

  [DC: smscomp] SMSServer sms = new cog SMSServer();
  [DC: telcomp] TelephoneServer tel = new cog TelephoneServer();
  [DC: smscomp] Balancer smsb = new cog Balancer();
  [DC: telcomp] Balancer telb = new cog Balancer();
  smsb!setPartner(telb);
  telb!setPartner(smsb);
  c = new cog Handset(1,tel,sms); ... // Clients handsets
}
```

Simply by commenting out the Balancer, we get the same functional behavior model without load balancing.

# Example 1: Phone Services - Simulation Results



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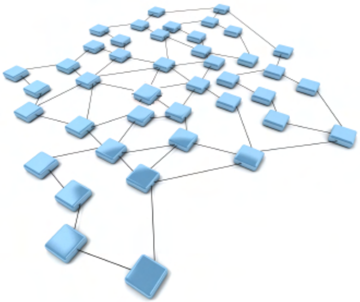
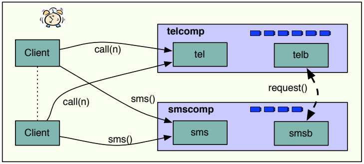
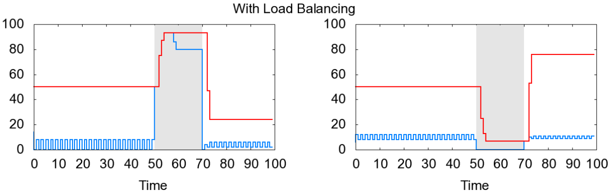


# Resource-Aware Applications

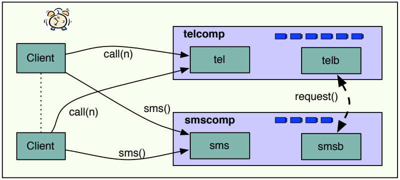
Applications that can administrate their resource usage
(e.g., to automatically adapt to changes in client traffic)



# Research Goal

*Develop a methodology to express and compare different deployment decisions for resource-aware distributed applications during the design phase.*




RQ1: Model deployment architectures

RQ2: Express deployment decisions

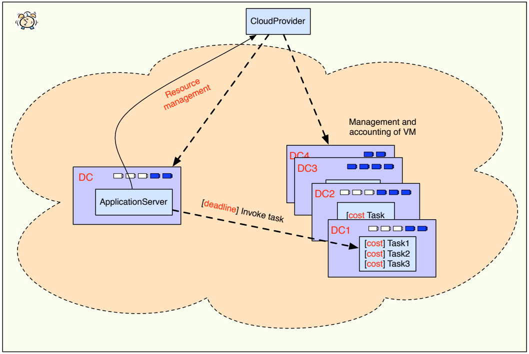
RQ3: Estimate and quantify QoS

RQ4: Compare deployment architectures

Model distributed applications that can adapt to changes in e.g., client traffic

# RQ1: How can we model deployment architectures for resource-aware distributed applications?

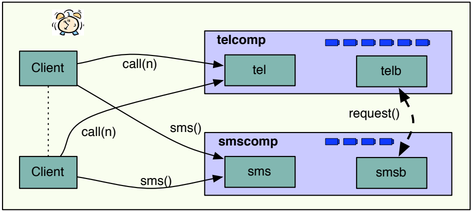
Deployment components to model physical or virtual deployment infrastructures



# RQ2: How can we express deployment decisions in models of resource-aware distributed applications?

**Design decisions related to QoS**

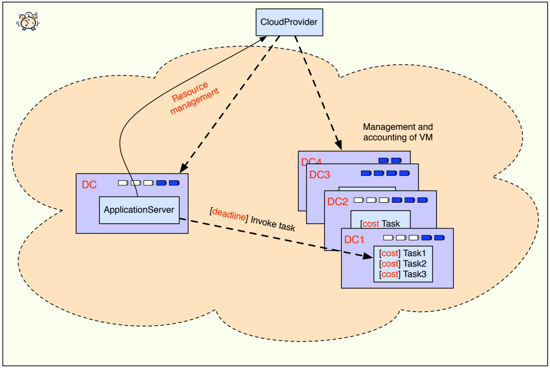
1. User-defined schedulers
2. Resource management primitives
3. Object migration




**Modeling of load-balancing strategies to improve performance**

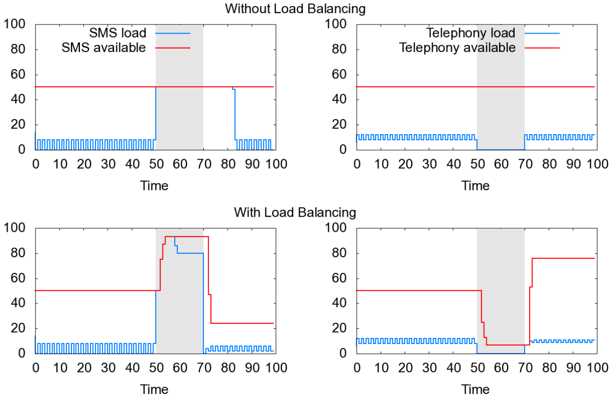
# RQ3: How can we estimate and quantify QoS in models of resource-aware distributed applications?

1. Time
2. Deployment components
3. Deadlines to method calls
4. Cost Annotations



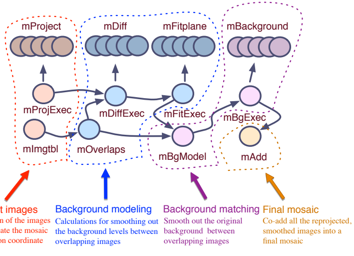
# RQ4: How can we compare deployment architectures in models of resource-aware distributed applications?

How performance of a model improves with resource-awareness.

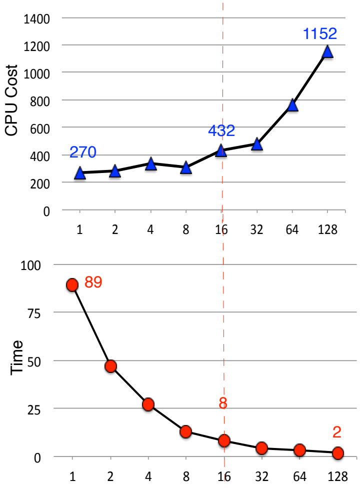


# RQ4: How can we compare deployment architectures in models of resource-aware distributed applications?

How we can compare execution time and execution cost.




Partly ordered workflow and highly parallelizable tasks.



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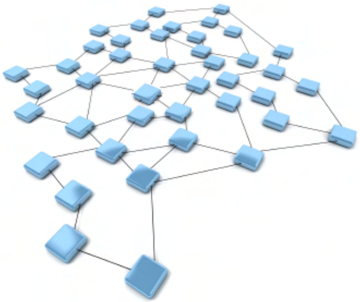

# Summary

- Syntactic and semantic extensions of Core ABS
  to express resource-awareness and compare deployment decisions:
  - Real-Time ABS: explicit and implicit modeling of time
  - Deployment components: modeling of deployment architectures
  - User-defined cost annotations
  - Deadlines to method calls
  - Resource management primitives
  - User-defined schedulers
- About the proposed methodology (validated with examples and case studies),
  the approach of this thesis allows:
  - to observe how the same functional model can behave under different deployment choices
  - to take better design decisions for resource-aware distributed applications during the design phase
  - to acquire better understanding of the trade-offs from the different deployment choices
  - to predict performance, scalability and resource costs

# Papers in this Thesis

1. User-defined Schedulers for Real-time Concurrent Objects.

   Joakim Bjørk, Frank S. de Boer, Einar Broch Johnsen, Rudolf Schlatte and Silvia Lizeth Tapia Tarifa.
   **Publication:** Journal of Innovations in Systems and Software Engineering, 2013.

2. Integrating Deployment Architectures and Resource Consumption in Timed Object-Oriented Models.

   Einar Broch Johnsen, Rudolf Schlatte and Silvia Lizeth Tapia Tarifa.
   **Publication:** Research Report 438, Department of Informatics, University of Oslo, February 2014. Journal of Logic and Algebraic Programming, accepted.

3. Modeling Resource-Aware Virtualized Applications for the Cloud in Real-Time ABS.

   Einar Broch Johnsen, Rudolf Schlatte and Silvia Lizeth Tapia Tarifa.
   **Publication:** Formal Methods and Software Engineering.
   Proceedings of the 14th International Conference on Formal Engineering Methods, ICFEM 2012.

4. Simulating Concurrent Behaviors with Worst-Case Cost Bounds.

   Elvira Albert, Samir Genaim, Miguel Gómez-Zamalloa, Einar Broch Johnsen, Rudolf Schlatte and Silvia Lizeth Tapia Tarifa.
   **Publication:** Proceedings of the 17th International Symposium on Formal Methods, FM 2011.

# Future Work

- Resources:
  - Other kind of resources (e.g., bandwidth, electric power)
  - User-defined resources
  - Multiple kinds of resources in the same deployment architecture
- Stronger analysis techniques, such as deductive verification
- Guarantee of contractual obligations related to QoS (e.g., integration of SLAs)
- Methodology extensions (e.g., stepwise development, code generation, model extraction, etc.)
- Model and analyze other non-functional requirements related to deployment (e.g., security, fault-tolerance)

THANK YOU