Karlsruhe Institute of Technology

Quantifying Software Correctness By Combining Architecture Modeling and Formal Program Analysis

KeY Symposium 2023

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Verification of Large Software Systems

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- Many components...

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- Many components…
- … with complex interactions…

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The QuAC approach:

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The Quac approach:

→ Modular analysis

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→ Modular analysis

→ Partial analysis
(of software and usage scenarios)

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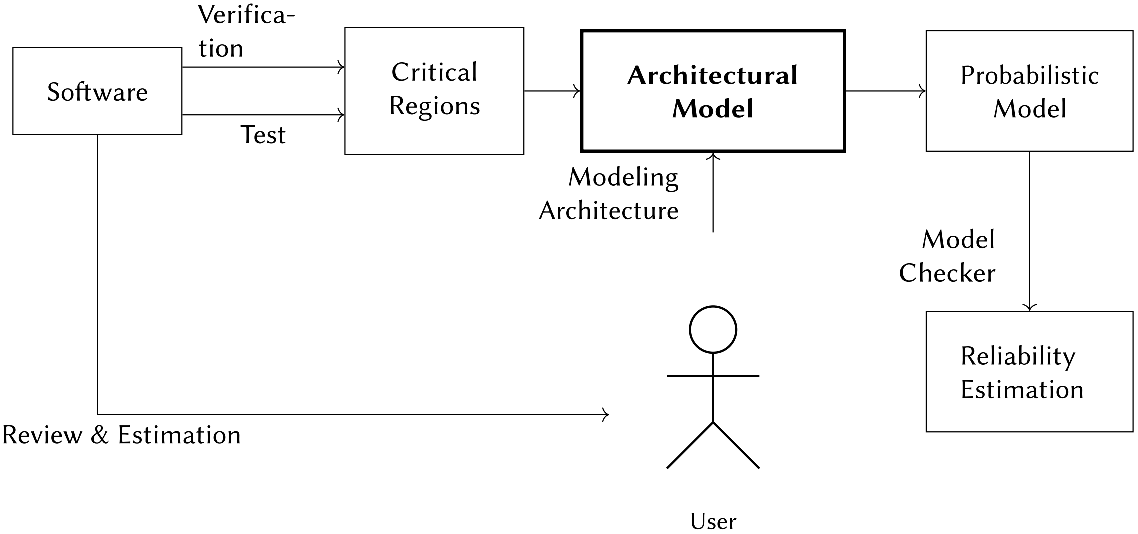
The QuAc approach:

→ Modular analysis

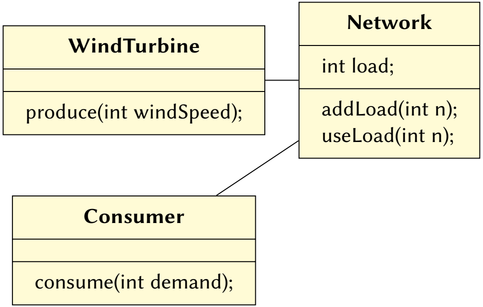
→ Partial analysis
(of software and usage scenarios)

→ Probabilistic model of usage scenarios

The QuAc Approach



Modeling Architecture and Behavior with Palladio



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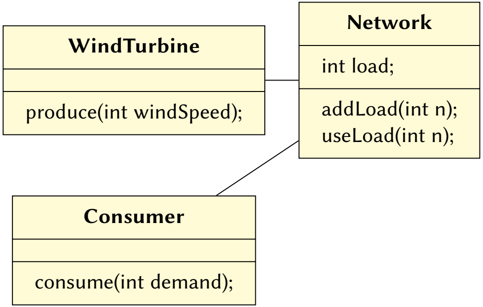
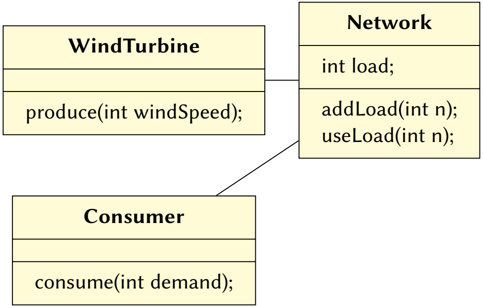


```
windSpeed ~ 𝒰(5,9);
demand ~ 𝒰(0,4);
windTurbine.produce(windSpeed);
consumer.consume(demand);
```

Modeling Architecture and Behavior with Palladio



WindTurbine

produce(int windSpeed);

Network

int load;

addLoad(int n);
useLoad(int n);

Consumer

consume(int demand);

```
windSpeed ~ 𝒰(5,9);
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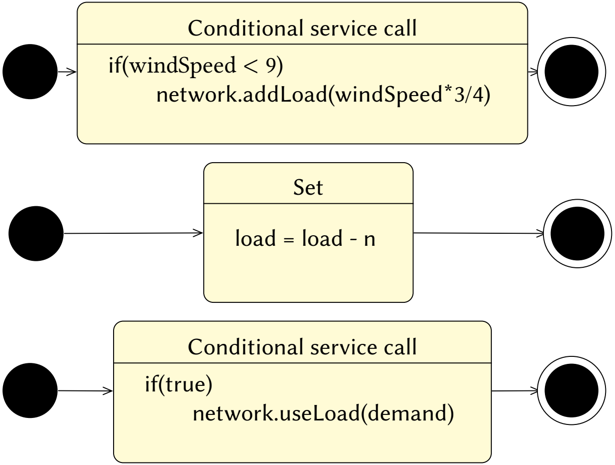


Conditional service call

if(windSpeed < 9)
    network.addLoad(windSpeed*3/4)

Set

load = load - n

Conditional service call

if(true)
    network.useLoad(demand)

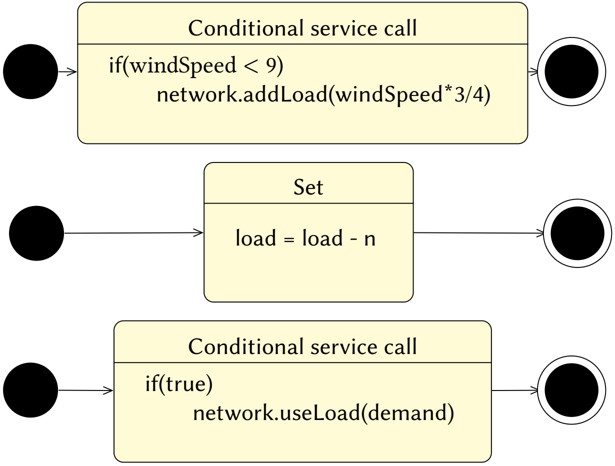
Implementing and Specifying Source Code

```
//@ invariant Network::load >= 0;

WindTurbine::produce(int windSpeed) {
  if (windSpeed < 9) {
    debuglog("producing");
    network.addLoad(windSpeed*3/4);
  }
}

void Network::addLoad(int n) { load += n; }
void Network::useLoad(int n) { load -= n; }

void Consumer::consume(int demand) {
  debuglog("consuming");
  network.useLoad(demand);
}
```



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Analyzing Source Code with KeY

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  network.useLoad(demand);
}
```

Open goals:

$$\begin{aligned} \text{produce} &\mapsto \emptyset \\ \text{addLoad} &\mapsto \emptyset \\ \text{useLoad} &\mapsto \{\phi \implies \psi, 0 \leq n + \text{self.load}\} \\ \text{consume} &\mapsto \emptyset \end{aligned}$$

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//@ invariant Network::load >= 0;

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Open goals:

$$\text{produce} \mapsto \text{false}$$

$$\text{addLoad} \mapsto \text{false}$$

$$\text{useLoad} \mapsto \bigvee_i \neg\phi_i \vee \bigvee_j \psi_j \vee 0 \leq n + \text{self.load}$$

$$\text{consume} \mapsto \text{false}$$

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Negated open goals:

$$\text{produce} \mapsto \text{false}$$

$$\text{addLoad} \mapsto \text{false}$$

$$\text{useLoad} \mapsto \bigwedge_i \phi_i \wedge \bigwedge_j \neg\psi_j \wedge \neg 0 \leq n + \text{self.load}$$

$$\text{consume} \mapsto \text{false}$$

Analyzing Source Code with KeY

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//@ invariant Network::load >= 0;

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Projected negated open goals:

$$\begin{aligned}\text{produce} &\mapsto \text{false}\\ \text{addLoad} &\mapsto \text{false}\\ \text{useLoad} &\mapsto 0 > n + \text{self.load}\\ \text{consume} &\mapsto \text{false}\end{aligned}$$

Analyzing Source Code with KeY

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//@ invariant Network::load >= 0;

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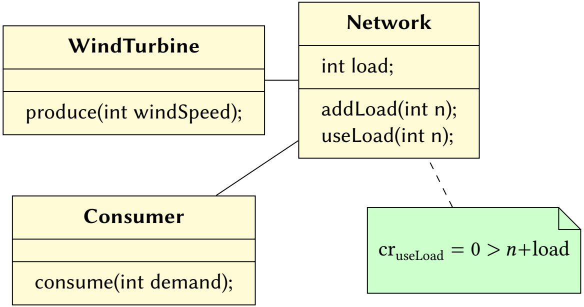
Critical regions:

$$\begin{aligned} \text{produce} &\mapsto \text{false} \\ \text{addLoad} &\mapsto \text{false} \\ \text{useLoad} &\mapsto 0 > n + \text{self.load} \\ \text{consume} &\mapsto \text{false} \end{aligned}$$

Extending Architecture Model with Analysis Results



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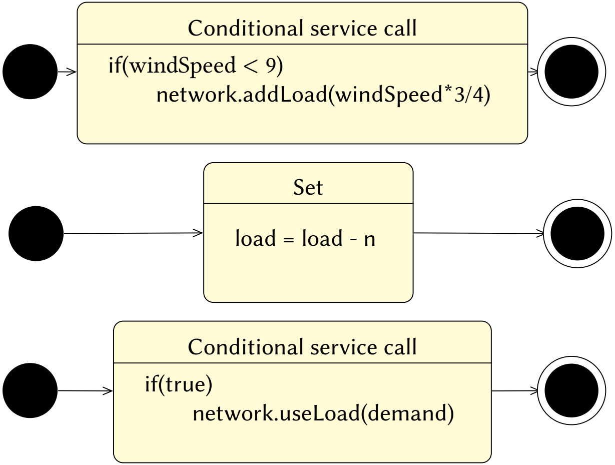

Transform Extended Architecture Model into Probabilistic Error Model

```
int load;

fun usageProfile():
  load = 0;
  windSpeed ~ U(5,9);
  demand ~ U(0,4);
  produce(windSpeed));
  consume(demand);

fun addLoad(int n):
  if (false): critreg;
  load = load + n;

fun useLoad(int n):
  if (0 > n + load): critreg;
  load = load - n;
```

```
fun produce(int windSpeed):
  if (false): critreg;
  if (windSpeed < 9):
    addLoad(windSpeed * 3 / 4);

fun consume(int demand):
  if (false): critreg;
  if (true): useLoad(demand);
```

Failure probability:

$$\text{Prob(error)} = \frac{1}{5}$$

Demo

Evaluation

- Works for example on the slides
- For realistic programs, exact computation scales terribly
  - Number of code paths
  - More importantly: Number of random variables
  - Perhaps potential for optimization
- Approximate model counting is feasible (run times mostly under 10 min.)

Conclusion and Outlook

- Quantitative analysis of **Safety**
  - Find critical parameter regions with KeY
  - Transfer critical regions into Palladio
  - Compute probability of reachability
    - Depends on usage model

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- Quantitative analysis of **Safety**
  - Find critical parameter regions with KeY
  - Transfer critical regions into Palladio
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    - Depends on usage model
- Outlook: Extension for **Security**
  - Attacker model:
    Attacker can manipulate service calls partially with certain probabilities/costs
    They use this to maximize the probability of entering a critical path