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Vision Paper: Towards Model-Based Energy Testing

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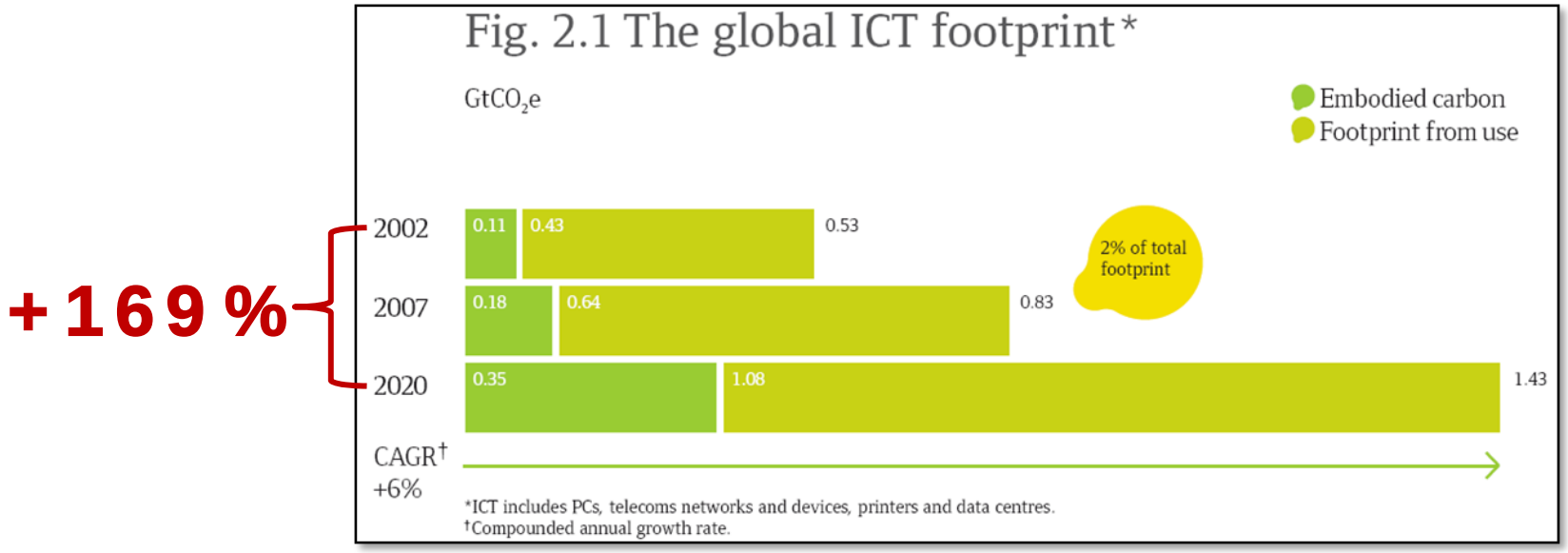
Problem

Today, energy consumption is an important issue for software development!

Problem: Ecological Aspect

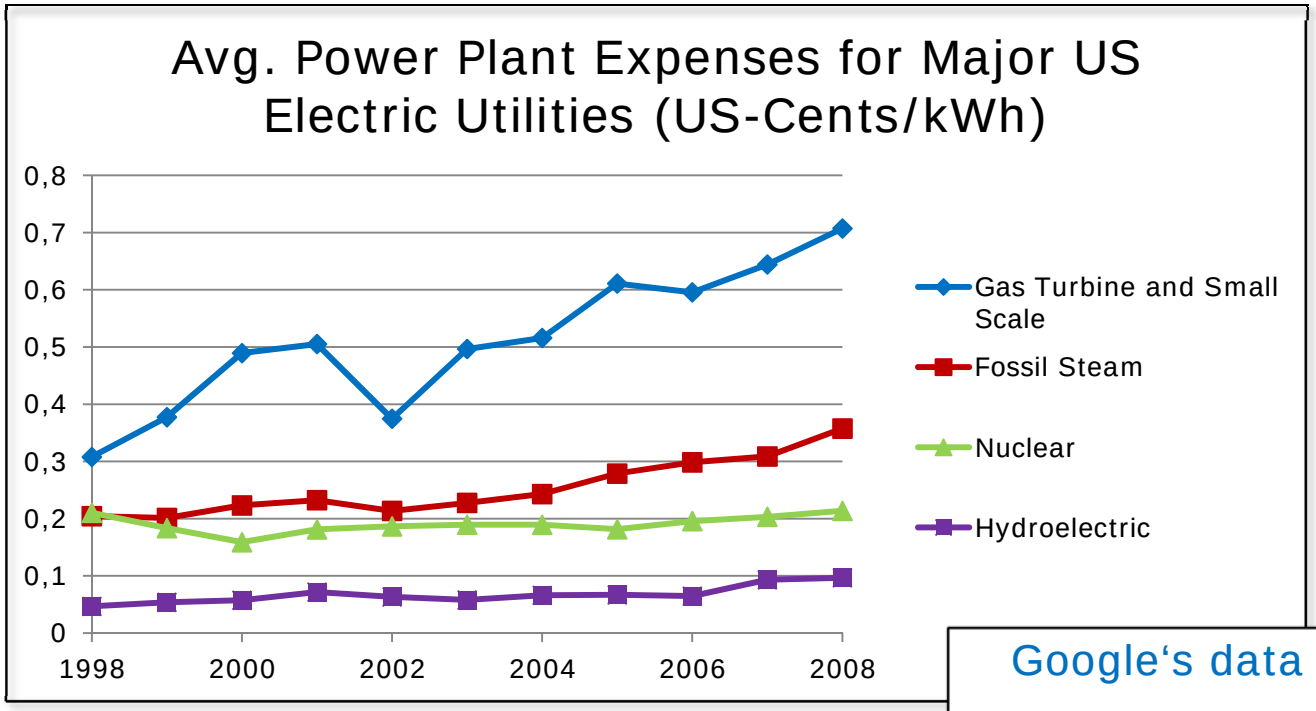
- **ICT's energy consumption is a global concern**
  - Gartner, Inc., 2007: 2% of world-wide C02 emissions [1]
  - SMART2020, 2008: 2% growing with 6% until 2020 [2]:



[1] Gartner, Inc.: Gartner Estimates ICT Industry Accounts for 2 Percent of Global CO2 Emissions. Gartner Press Release, April 2007.

[2] The Climate Group: SMART 2020: Enabling the low carbon economy in the information age. Report on behalf of the Global eSustainability Initiative (GeSI), 2008.

Problem: Economical Aspect



[3]

+86.9%

+97.9%

+3.2%

+79.4%

Google‘s data centers in 2010 [4]:

2 260 000 000 kWh

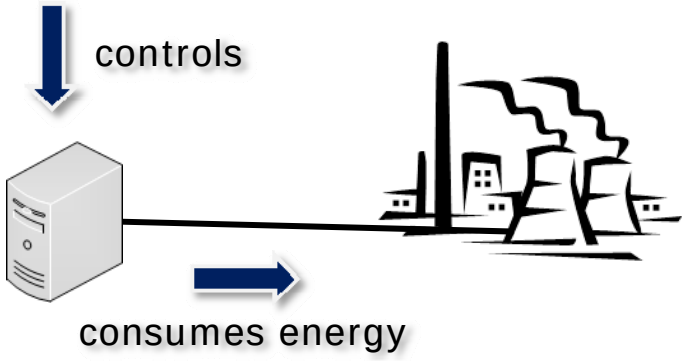
[3] U.S. Energy Information Administration: Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities, April 2011. http://www.eia.gov/electricity/data.cfm#sales

[4] 2,26 Terrawattstunden – Google legt Energiebedarf offen. Article @ Golem.de, September 2011. http://www.golem.de/1109/86335.html

Software Consumes Energy?

- **SW consumes energy indirectly**
  - CPU utilization
  - Read/write on HDD
  - Network traffic
  - …
- **HW works (partly) energy-efficient**
  - Power saving modes busy, idle, sleep, …

```
public class Main {
  public static void
      main(String args[]) {
    for (int i = 0; i <
        Math.round(Math.random()
        * 5); i++) {
      System.out.println(i);
    }
  }
}
```



- **But: SW influences HW‘s state and energy consumption**
  - Polling
  - Continuous read/write

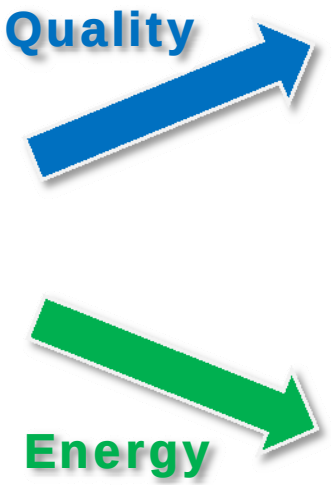
→ ***Hardware optimization is not enough***

Problem: Summary

- **Energy consumption should be optimized**
  - Target: quality improvement, energy decrease
- **Optimization includes testing**
  - E.g., regression testing to ensure decreasing energy consumption during optimization

→ ***Need for systematic facilities***

1. Testing at the code level
2. Static energy analysis
3. Automated (model-based) testing



Challenge #1

Energy Testing

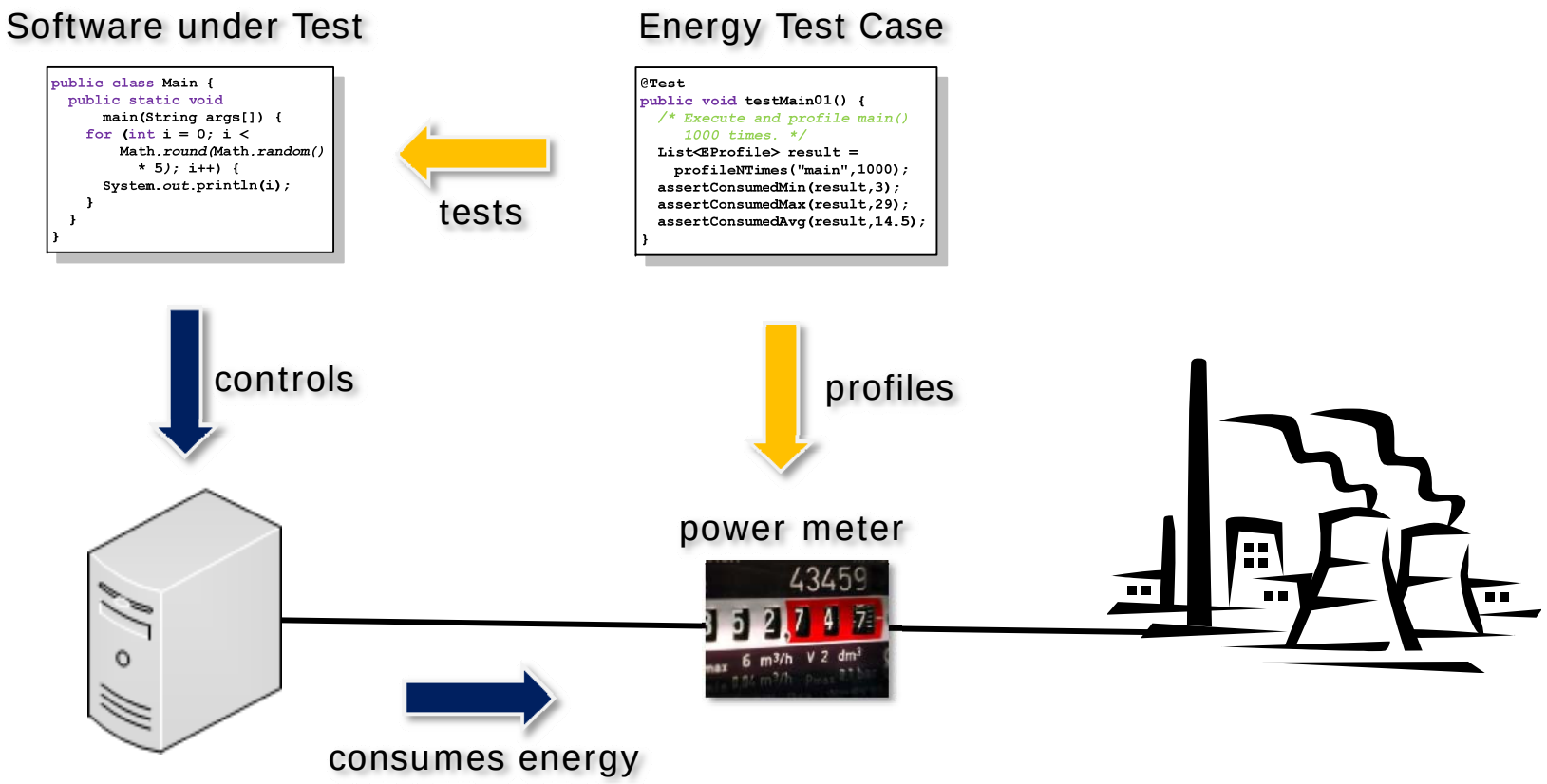
Challenge #1: Energy Testing

- **Testing of energy requirements at the code level**

- **Similar to functional unit and regression testing**
  - Initialize objects
  - Invoke operations
  - Compare results
  - ***Check energy consumption of test runs (workloads)***

- **Energy testing is**
  1. Workload execution
  2. Profiling
  3. Energy assertions

Need for an Energy Testing Framework



Energy Testing Challenges (1/2)

- **Workload execution**
  - Test runners already exist (e.g., JUnit)

- **Profiling energy consumption**
  - Granularity
    - Complete devices
    - Single hardware elements
  - Reusability
    - PCs, Laptops
    - Smart phones, Tablets
    - Robots and other embedded systems
  - Accuracy
    - Probe frequency
    - Noise of operating system
    - Noise of applications running in parallel
    - Probe effects

Energy Testing Challenges (2/2)

- **Assertions**
  - Energy unit tests
  - Energy regression tests
  - Device-independent design of assertions?

Work in Progress: JouleUnit

- **Energy testing framework for Java**
  - Workload execution: JUnit
  - Profiling: battery sensors and external power meters
  - Energy assertions for unit and regression testing

```
JouleProfiler profiler = new JouleProfiler();
profiler.startProfiling();

/* Run the workload here. */

EnergyProfile profile = profiler.endProfiling();

assertMaxJoules(profile, 30000);
assertMaxWatts(profile, 40000);
assertBestEver("test01", profile);
```

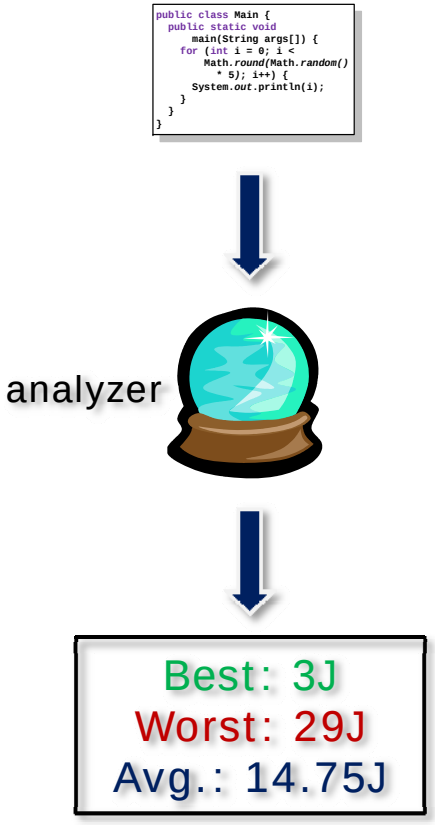
- **More information:** http://www.jouleunit.org/

Challenge #2

Static Energy Consumption Analysis

Challenge #2: Static Analysis

- **Predict an application's energy consumption**
  - Do not execute the application
  - But predict its energy behavior
  - → ***Early design decisions***
- **Estimation of bounds**
  - Lower, upper bounds (best/worst case)
  - Average consumption
- **Use of static analysis**
  1. Evaluate energy consumption for individual statements / building blocks
  2. Execute / interpret the application abstractly
  3. Evaluate the predictions w.r.t. Accuracy / Probability



Static Analysis of Energy Behavior

- **Static analysis of code → *Abstract interpretation* [5]**

```
public class Main {
  public static void main(String args[]) {
    int i;
   {i = null}            {E >= 1J, E <= 1J}
    for (i = 0; i < Math.round(Math.random() * 5); i++) {
   {i >= 0, i <= 5}     {E >= 2J, E <= 26J}
      System.out.println(i);
    }
   {i >= 0, i <= 5}     {E >= 3J, E <= 29J}
  }
}
```

Classical: **Energy:**

i = [0, 5] **E = [3J, 29J]**

[5] Cousot, P., Cousot, R.: Abstract interpretation: a unified lattice model for static analysis of programs by construction or approximation of fixpoints. In: Proceedings of the 4th ACM SIGACT-SIGPLAN symposium on Principles of programming languages, ACM, 1977, p. 238-252.

Energy Consumption of Building Blocks

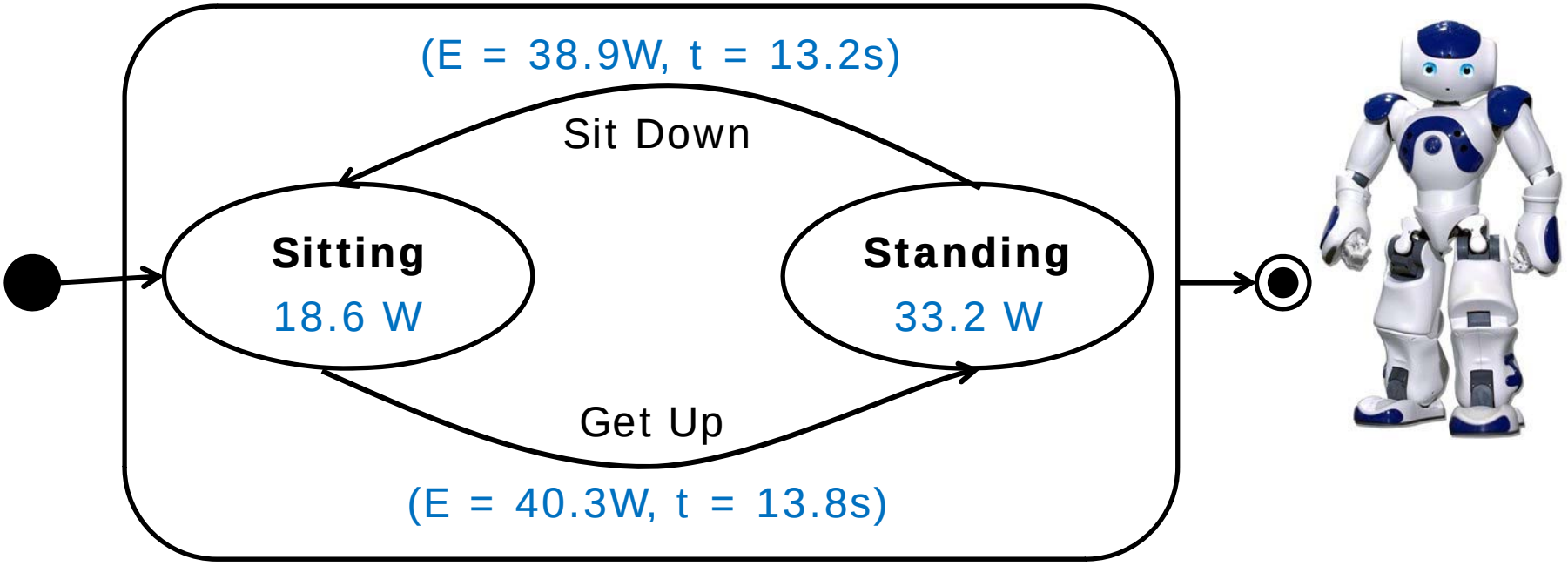
- **Possible for individual program instructions?**
  - Possible for Java byte code subsets [6]
    - Only for specific hardware
    - How to do this hardware independently / configurable?
  - What about non-deterministic behavior?
    - External inputs
    - Database access
    - External configuration
      e.g., System.out.println();

- **Possible for larger instruction blocks or services?**
  - Energy consumption of a method call?
  - What about parameters and non deterministic behaviors?

[6] Lafond, S., Lilius, J.: An Energy Consumption Model for an Embedded Java Virtual Machine. In: Architecture of Computing Systems - ARCS 2006. Volume 3894 of LNCS. Springer Berlin / Heidelberg, 2006, p. 311-325.

Static Analysis of Energy Behavior

- **Possible for other abstraction layers as well**
  - E.g.: a state chart describing a robot's behavior
  - Program to analyze is a workload of events and wait intervals:
    `wait 5s; get up; wait 2s; sit down;`



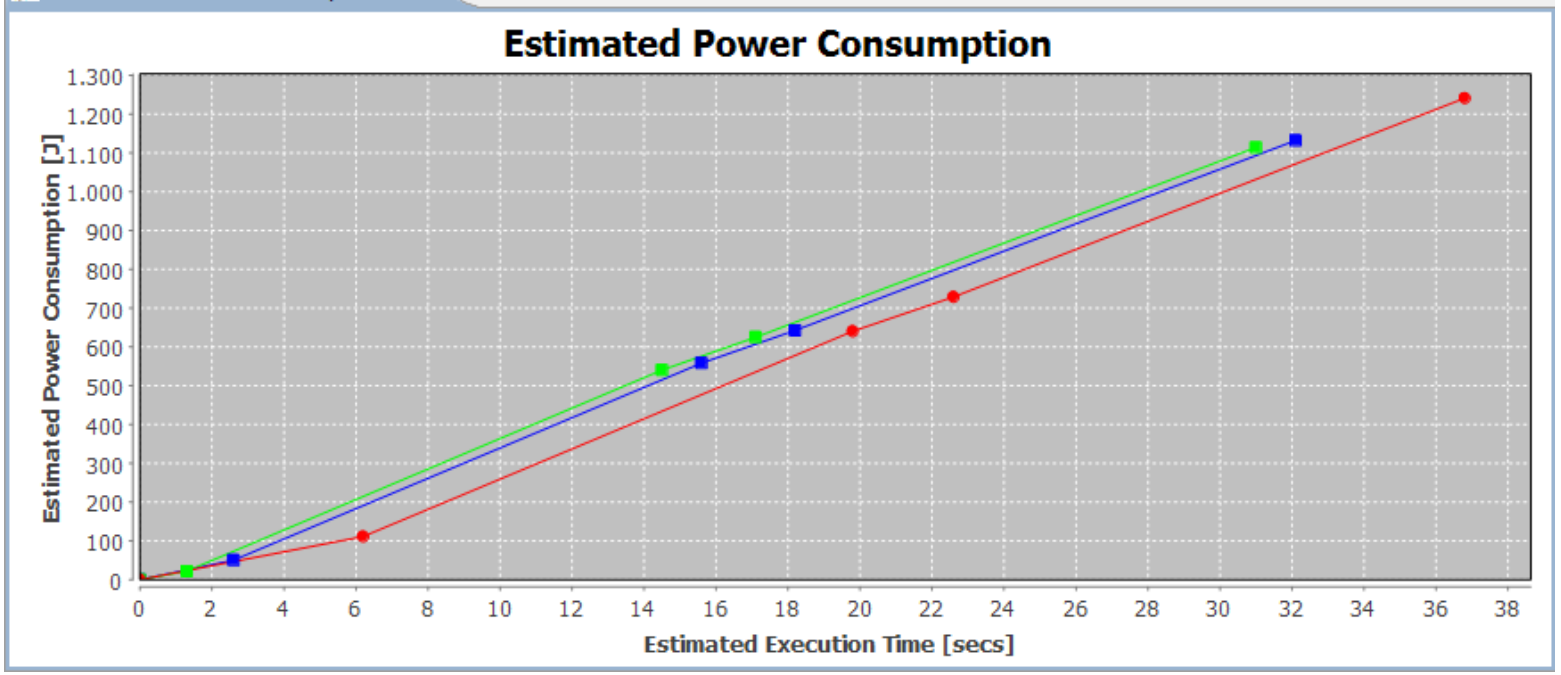
Static Analysis: First Results

test2.naot

```
NAO Chuck IP 192.168.0.139 PORT 8070

Chuck say "Hello everybody."
Chuck get up
Chuck say "I am profiled during this program."
Chuck sit down
```

Predicted Non-Functional Properties



Static Analysis Challenges

- **What is the right abstraction layer?**
  - Individual programming language instructions
  - Larger units: components
- **How to handle different types of statements / blocks [7]:**
  - Constant consumption
  - Parameter/context-dependent consumption
  - Unpredictable consumption
- **Can we build static energy optimizers?**
  - Reordering of instructions
  - Proposition of energy-critical blocks

[7] Seo, C., Malek, S., Medvidovic, N.: An Energy Consumption Framework for Distributed Java-Based Systems. In: Proceedings of the 22nd IEEE/ACM Intl. Conference on Automated Software Engineering, Atlanta, Georgia, USA. ACM, New York (2007).

Challenge #3

Towards Model-Based Energy Testing

Model-Based Energy Testing (MBET)

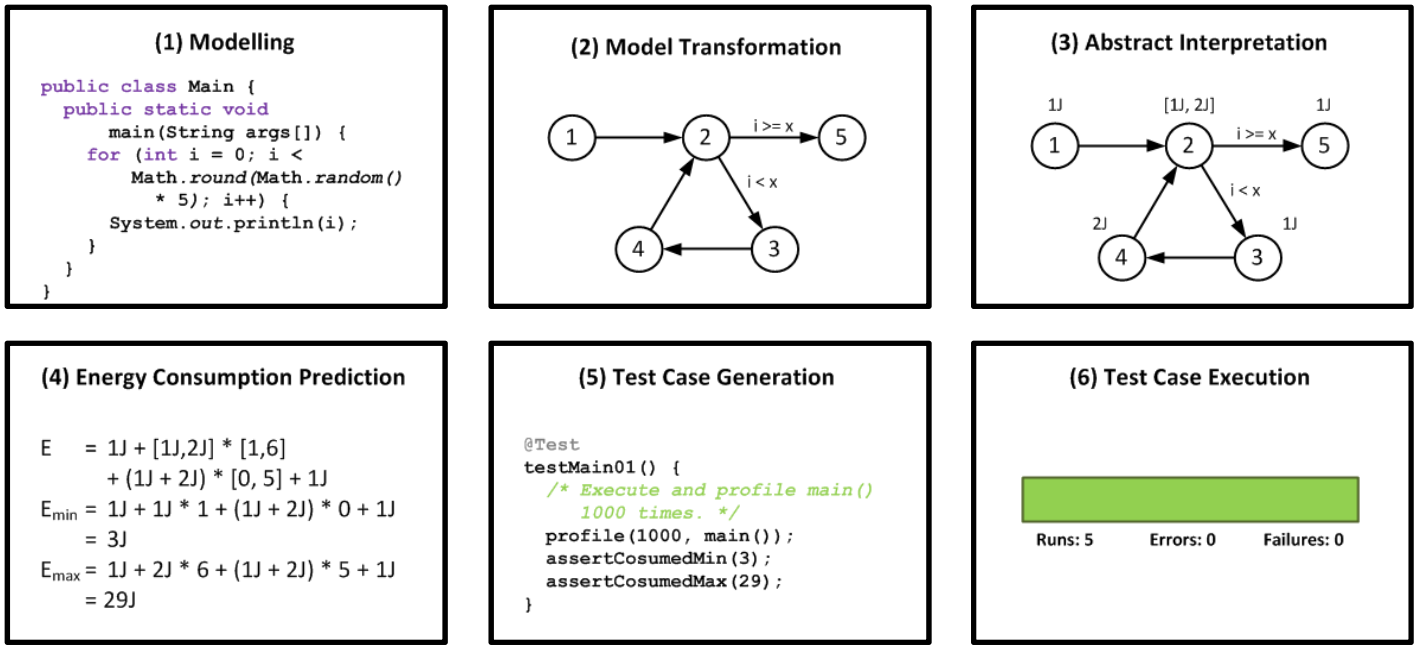
- **Model-Based Testing (MBT) [8]:**
  "The automatable derivation of concrete test cases from abstract formal models, and their execution."

- **Model-Based Energy Testing (MBET):**
  Apply techniques from MBT to energy testing

[8] Utting, M., Pretschner, A., Legeard, B.: A Taxonomy of Model-Based Testing. Technical Report 04/2006, University of Waikato, Department of Computer Science, Hamilton, 2006.

MBET using Static Analysis?

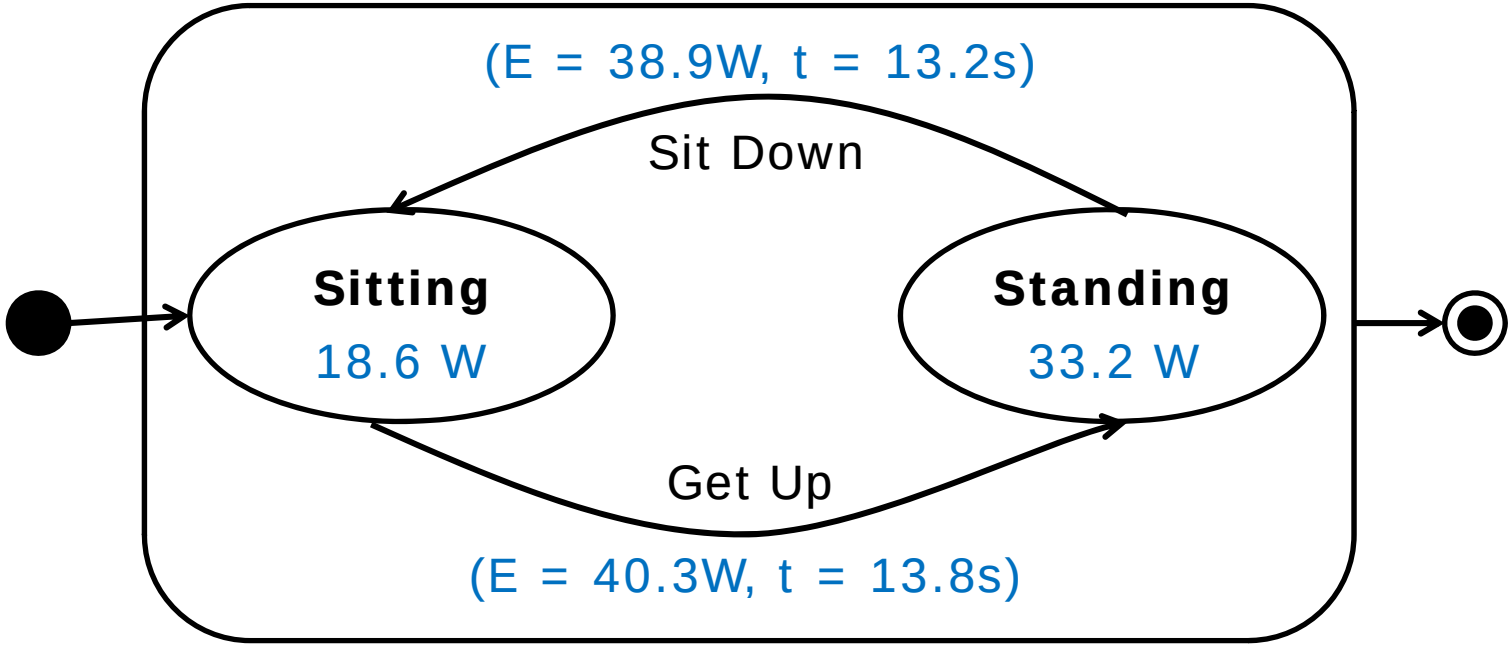
- **Generating test cases from static analysis**
  - Static analysis predicts energy consumption for workloads
  - Predictions can be transformed into energy assertions:



- ***Test cases for static analysis or test case for SUT?***

MBET from Energy State Charts?

- **Derive sensible workloads from behavior models**



- State coverage, transition coverage, path coverage, …
- Does energy testing require new coverage criteria?

MBET Challenges

- **How does a MBET process looks like?**
  - Use of static analysis?
  - Workload generation?
  - Derive energy test cases from requirement models?
- **What is the optimal / right model for MBET?**
  - Behavior model
  - Energy consumption model
- **How different is MBET from classical MBT techniques?**

Summary

Summary

- **Testing and optimization facilities for energy are necessary**
  - Ecological aspect
  - Economical aspect
- **Energy testing at the code level**
  - Workload execution
  - Profiling
  - Energy unit and regression testing
- **Static analysis for energy consumption**
  - Abstract interpretation of code
  - Abstract interpretation of models (state charts)
- **Model-Based approaches for Energy Testing**

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Thank You!

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