Collaboration Among Software Components

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Portland State
UNIVERSITY

Summary of the Talk

Questions

- What can unit testing do in principle?
- For what kind of code does unit testing work?

Background

- Unit testing here and there
- *Software components* are nice units
- Component-based software development (CBSD)
- Subdomain testing tools to synthesize CB systems

Results

- Pitfalls of component testing in CBSD
- Design rules in aid of component testing
- A new development/testing scheme

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But everyone hopes it will help...

What Do the Other Engineers Do?

Designing a Vacuum System from Components

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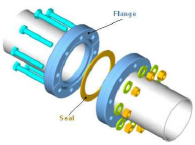
Designing a Vacuum System from Components

1. Choose components from catalog



(http://us.trinos.com)

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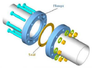
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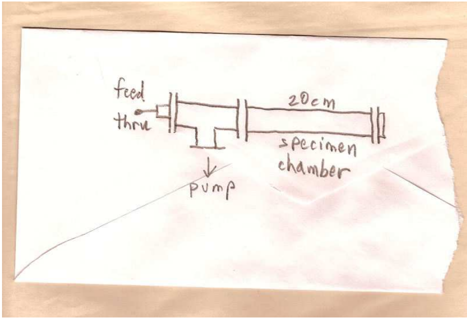

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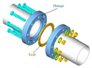

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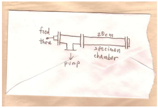

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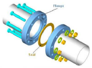

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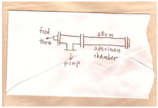

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   - Oops! Need more volume, use 80mm ID
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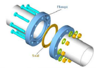

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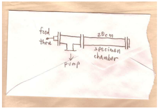

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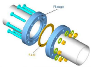

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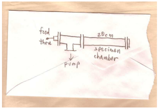

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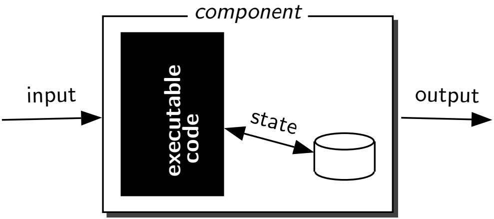
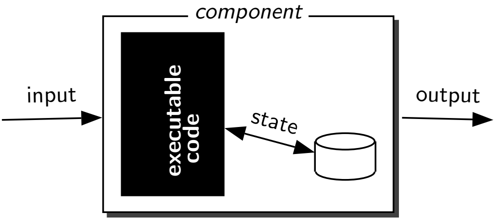
Would that it were so in software!

Software Components



Software Components

- Executable code
- Interface
- Black-box behavior
- Local state



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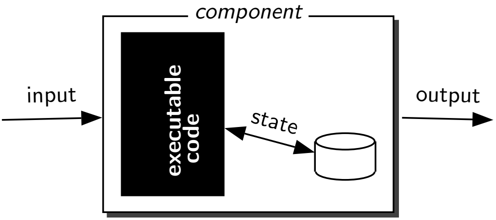

Why components?

- Reuse is better, cheaper (?)
- Precise software “units”
- Sidestep programming-language and design issues

Component-based Software Development (CBSD)

Components

- Specified, designed, implemented, tested *in isolation*
- Later to be used in systems *without modification*
- *component catalog* records data for later use

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Systems

- Assembled by matching components' interfaces
- Combination scheme is the system *architecture*
- In principle, design is done from the component catalog
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Ideal context for studying unit vs. system testing

Subdomain Testing Tools

Describe components and systems with configuration files

- Component description
  - Executable code file (any source language)
  - Subdomain decomposition of the domain
- System architecture
  - Flowgraph of component connections

Subdomain Testing Tools

Simplifying restrictions

Floating-point values on each execution:

1. One input value (read `STDIN`)
2. One output value (write `STDOUT`)
3. One non-functional value (run time) reported (write `STDERR`)
4. One state value read/written (disk file)

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Why so restricted?

- Simplify a complex situation to study it
- A small research group can implement powerful tools

A Component Description

A sawtooth with three ‘teeth’ modulated by an inverted parabola

saw.ccf

```
saw.bin
0 0.416666666666625 5
0.416666666666625 0.83333333333325 5
0.83333333333325 1.24999999999987 5
1.24999999999987 1.6666666666665 5
1.6666666666665 2.08333333333313 5
2.08333333333313 2.49999999999975 5
2.49999999999975 2.91666666666637 5
2.91666666666637 3.333333333333 5
3.333333333333 3.74999999999975 5
3.74999999999975 4.1666666666665 5
4.1666666666665 4.58333333333325 5
4.58333333333325 5 5
5 5.41666666666675 5
5.41666666666675 5.8333333333335 5
5.8333333333335 6.25000000000025 5
6.25000000000025 6.666666666667 5
6.666666666667 7.08333333333363 5
7.08333333333363 7.50000000000025 5
7.50000000000025 7.91666666666687 5
7.91666666666687 8.3333333333335 5
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9.16666666666675 9.58333333333337 5
9.58333333333337 10 5
```

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```
#!/usr/bin/perl -w
#
# executable  saw.bin
#
# sawtooth with parabolic envelope
$cycles = 3; #number of "teeth"
$interval = 10.0; #[0,10)
$env = 10.0;
$X = <STDIN>;  #read input
$Y = $X*$env*$cycles/$interval;
$Y -= int($env)*int($Y/$env);  #sawtooth
$Y *= 1.0 - (($X-6)**2)/(36);  #parabola
print "$Y\n";  #write output
print STDERR "1.0\n";  #constant 'run time'
```

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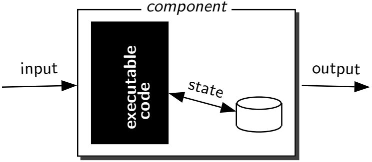

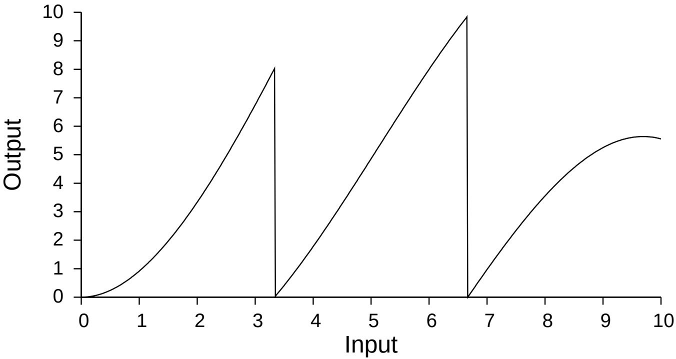

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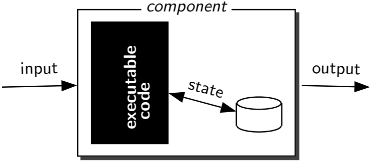

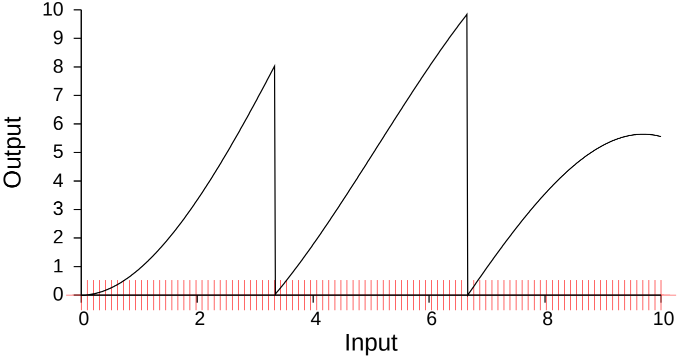

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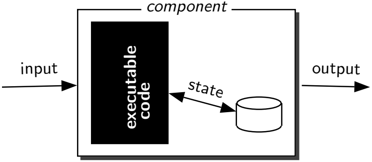

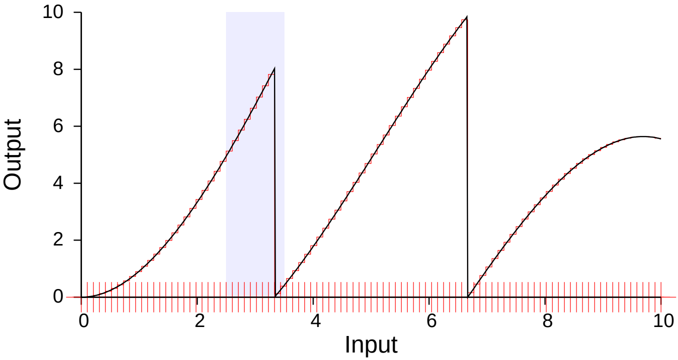

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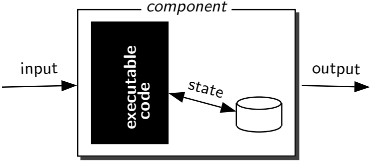
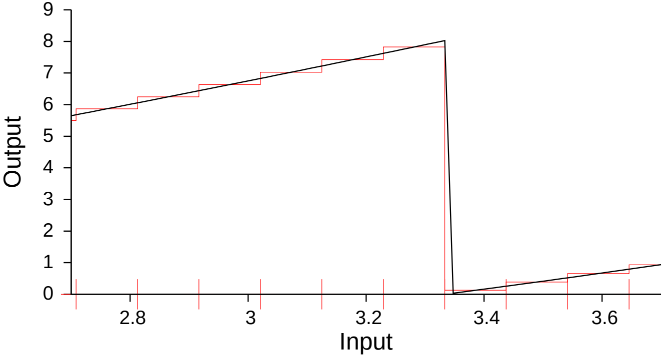
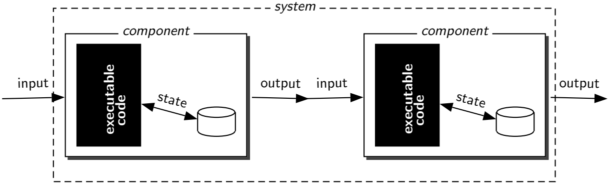




Predicting System Behavior

Two copies of the sawtooth in series



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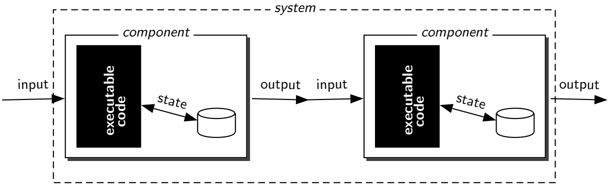


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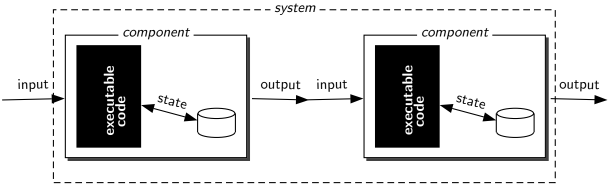

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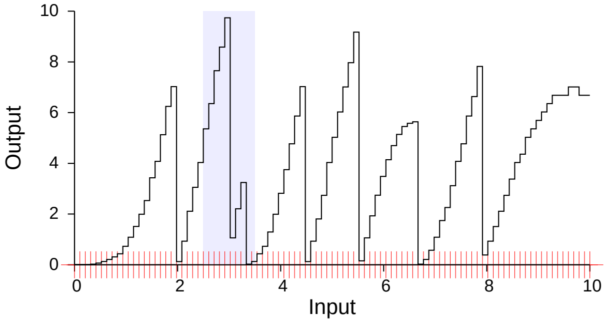

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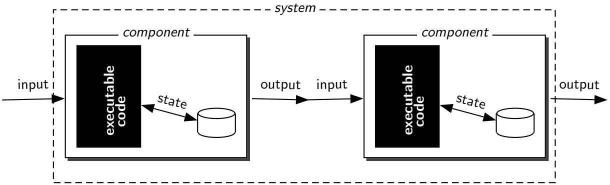

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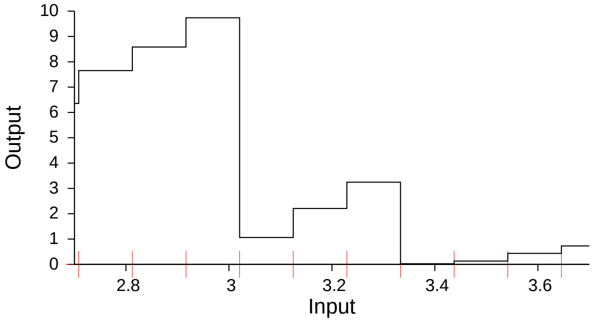
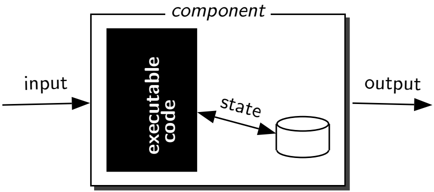


A Component with State

- On non-negative inputs 0..9, store count of longest sequence
- On negative inputs -10..-1, return stored sequence counts (for 9..0)



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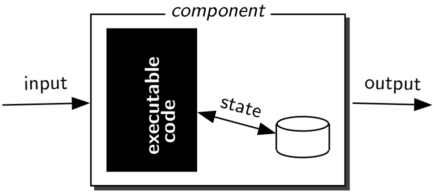

Example:

−1	1	0	−1	1	1	5	−2
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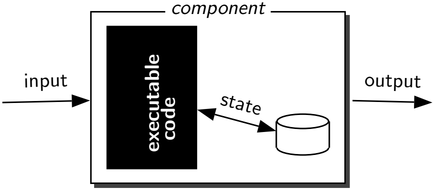

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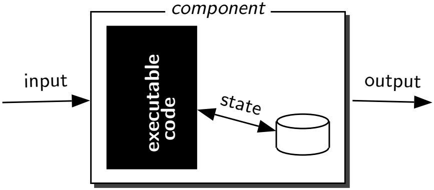

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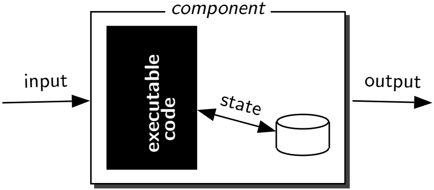

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maximum zero sequence *maximum one sequence*

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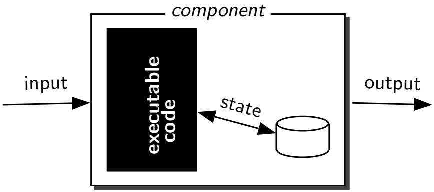

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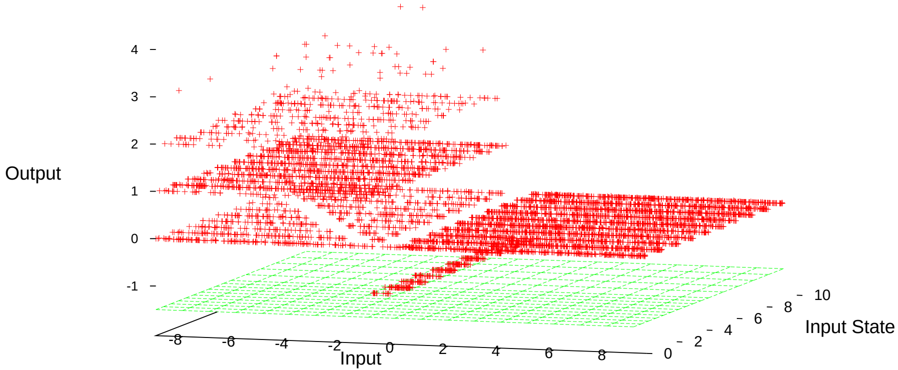
maximum five sequence

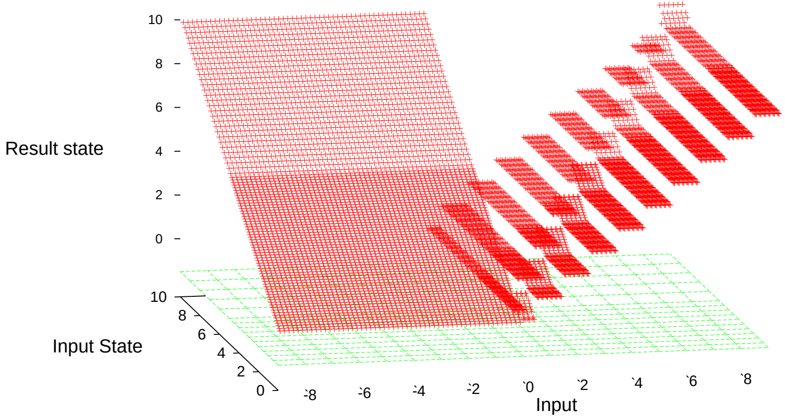
Component Output Behavior

Random-length sequences of random test points:



Component Result-state Behavior

Systematic coverage of (input $\times$ state) pairs:



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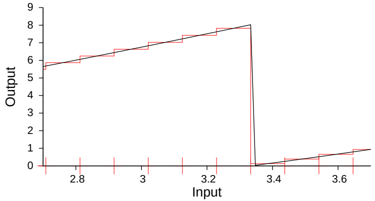
Approximation Errors

- Component measurement:



subdomain	*r-m-s error*
$[2.81, 2.92)$	2.93
$[2.92, 3.02)$	2.97
$[3.02, 3.12)$	3.01
$[3.12, 3.23)$	3.05
$[3.23, 3.33)$	3.08
$[3.33, 3.44)$	1.95
$[3.44, 3.54)$	2.02

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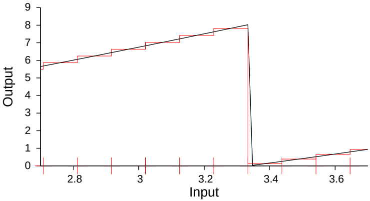

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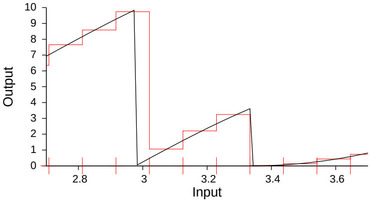
- System prediction:



subdomain	*r-m-s error*
$[2.81, 2.92)$	7.00
$[2.92, 3.02)$	125.17
$[3.02, 3.12)$	7.30
$[3.12, 3.23)$	7.30
$[3.23, 3.33)$	6.97
$[3.33, 3.44)$	0.40
$[3.44, 3.54)$	1.19

Spurious-state Sampling

How to test components/systems with state?

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- For $i = 1, 2, 3, ..., N$:
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  - Choose input X_i
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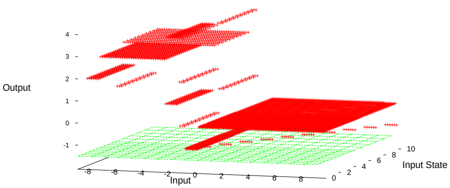
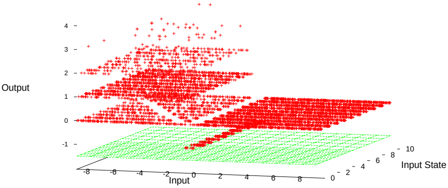
- Execute on input X_0 to initialize ('reset') state to S_0
- Check S_0 and output against specification
- For $i = 1, 2, 3, ..., N$:
  - Choose input X_i
  - Execute on input X_i (state is S_{i-1})
  - Compare result state S_i and output with specification

State Sampling vs. Input Sequences

Systematic state sampling

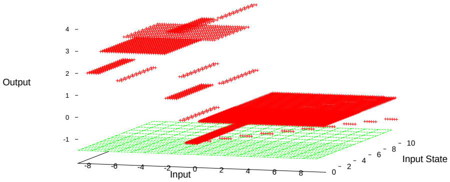


Random input sequences

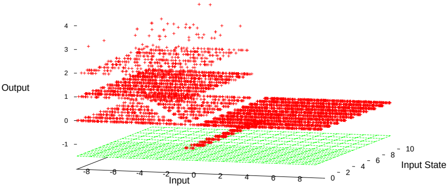


State Sampling vs. Input Sequences

Systematic state sampling



Random input sequences



Sampling infeasible states:

- Wastes scarce testing time
- Distorts the real behavior
- Hides unexpected real states
- Worst case: specified states are infeasible

The Internal Profile Problem

Each component distorts the profile it receives

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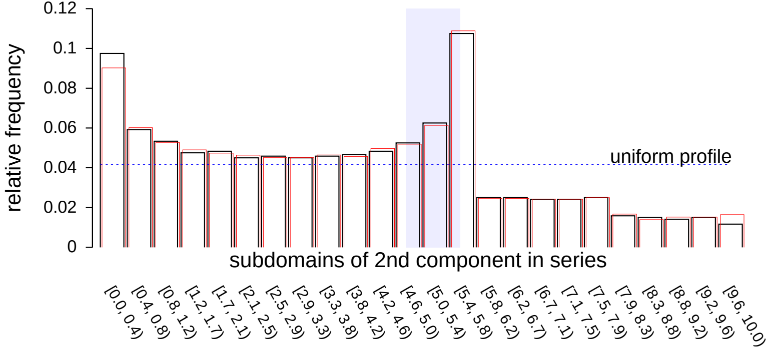
For the two sawtooth components in series:



The Internal Profile Problem

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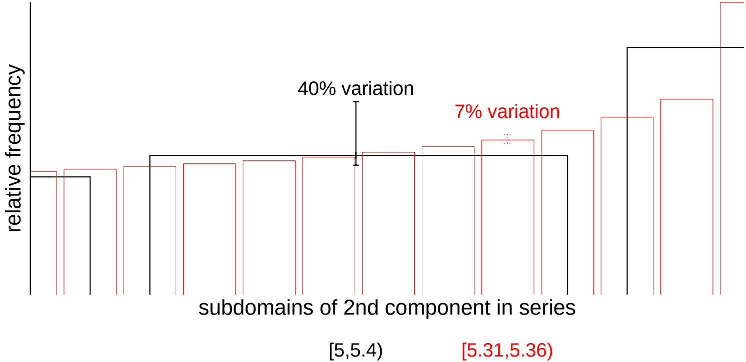

The same thing happens within a subdomain

Design Rules

Design Rule 1

Check calculated system profiles against component test profiles

Derived Rule 1-1

Don't use a general-purpose component for a few specific values

Design Rule 4

Group state values within as few components as possible – don't create cross-product states

Derived Rule 4-1

Group all 'modes' (preferences) in a control component; test all combinations

A New Component-based Development Scheme

1. Develop and test components $\rightarrow$ quantitative descriptions (or get quantitative descriptions from component catalog)

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That's what the other engineers do...

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CAD Calculation ❸ is *much* faster and easier than system testing

Summary of the Talk

Questions

- What can unit testing do in principle?
- For what kind of code does unit testing work?

Background

- Unit testing here and there
- *Software components* are nice units
- Component-based software development (CBSD)
- Subdomain testing tools to synthesize CB systems

Results

- Pitfalls of component testing in CBSD
- Design rules in aid of component testing
- A new development/testing scheme