Formal Methods for C

Seminar – Summer Semester 2014

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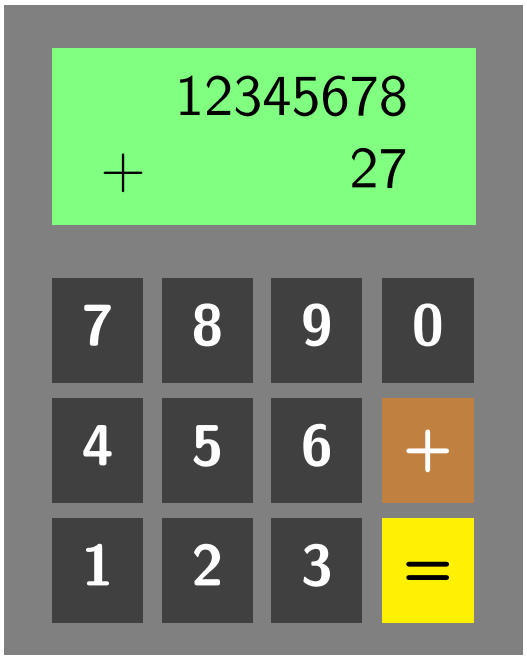
Formal Methods

Once Upon a Time...

Provably Correct vs. Testing: Pocket Calculator



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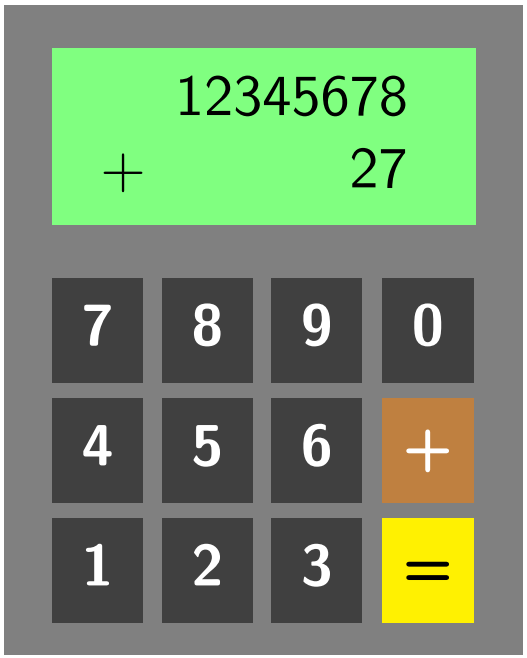

- Requirement:
  If x, $+$, and y are displayed then after pressing =,
  the sum of x and y is displayed if $x + y$ has at most 8 digits,
  otherwise "-E-" is displayed.

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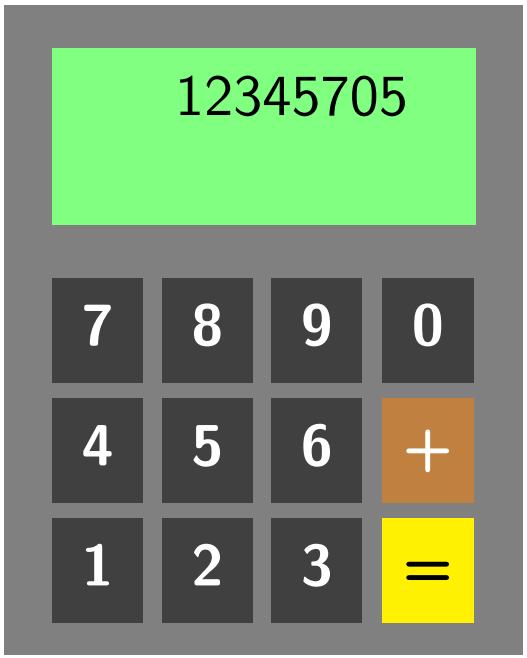

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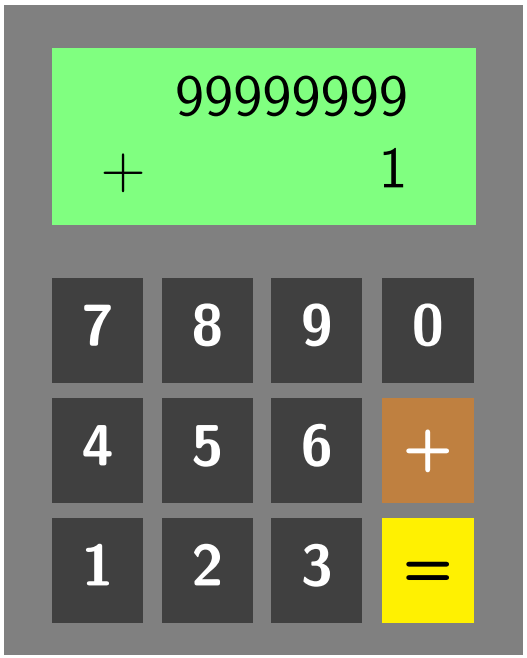

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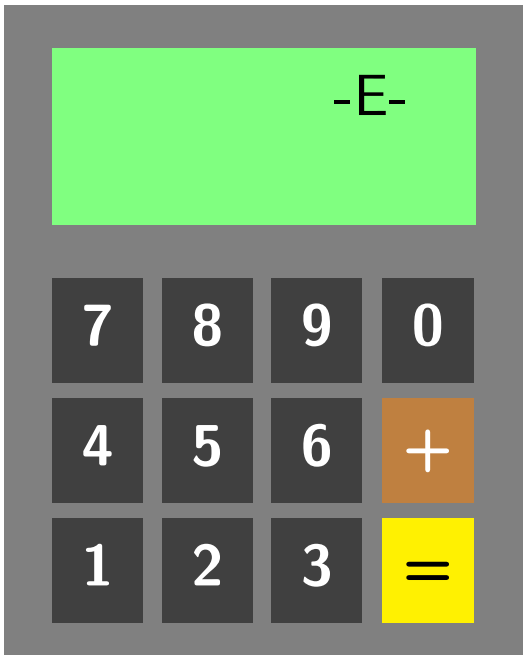

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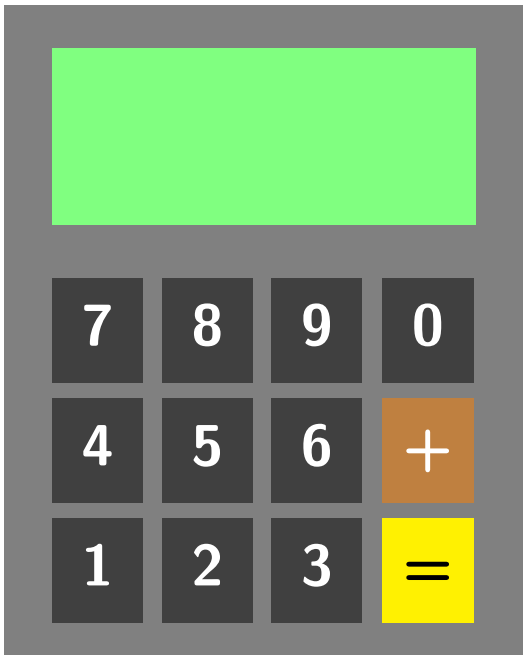

Test some representatives of "equivalence classes":

- $n + 1$, n small, e.g. $27 + 1$
- $n + m$, n small, m small (for non error), e.g. $13 + 27$
- $n + m$, n big, m big (for non error), e.g. $12345 + 678$
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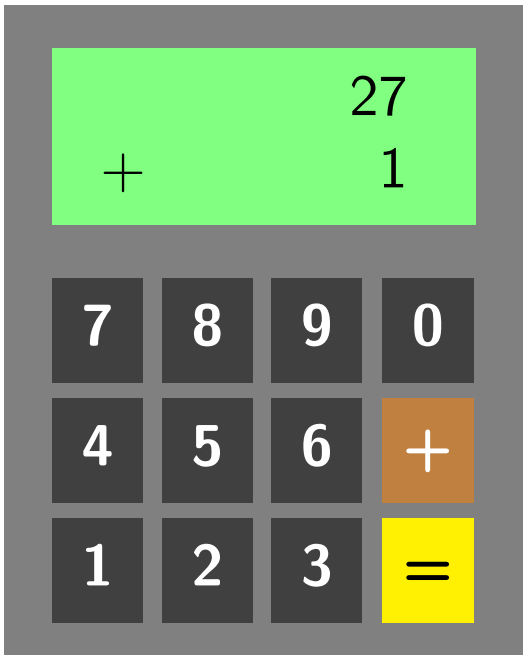

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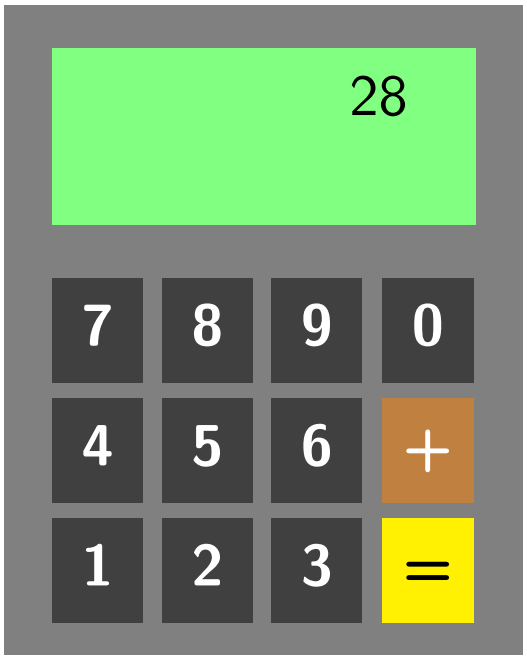

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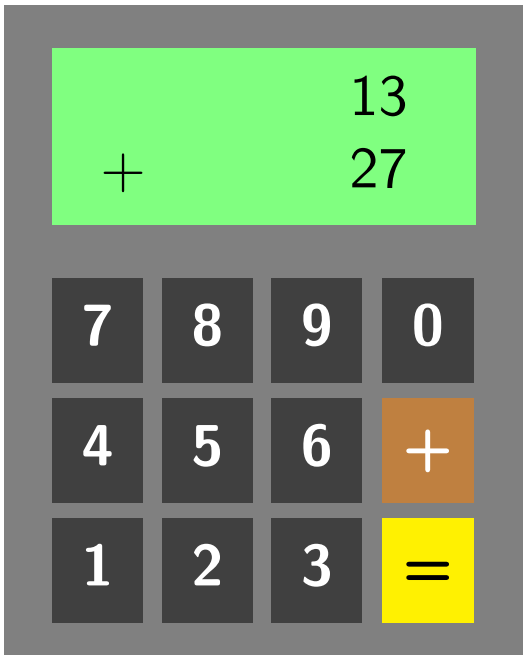

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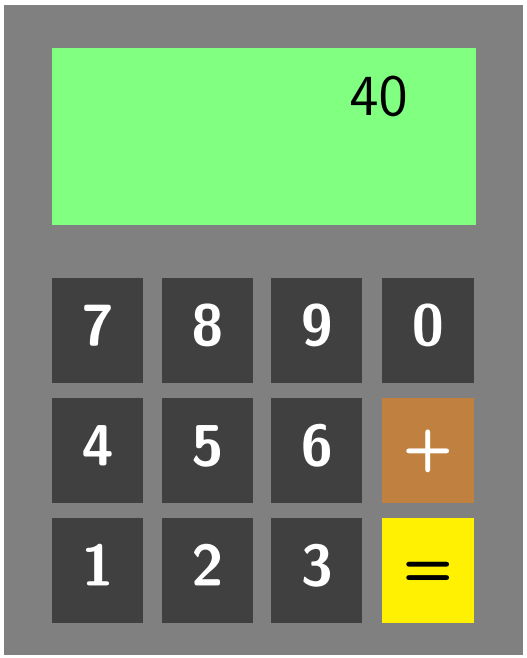

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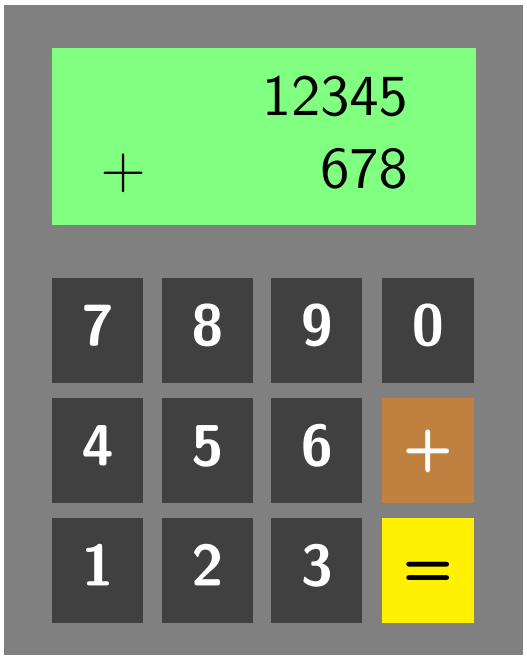

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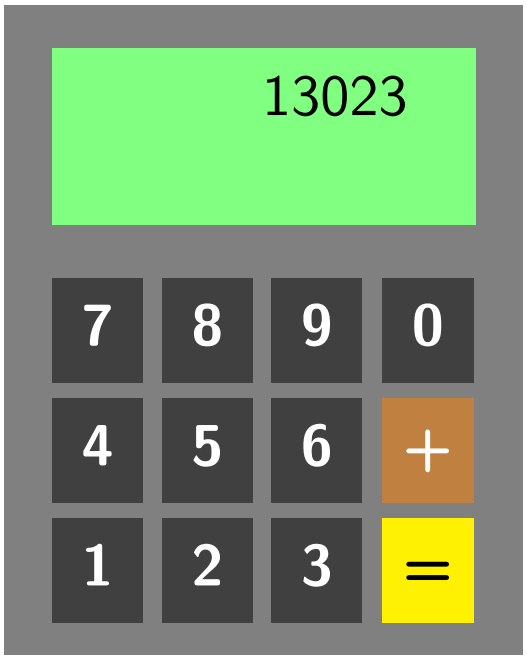

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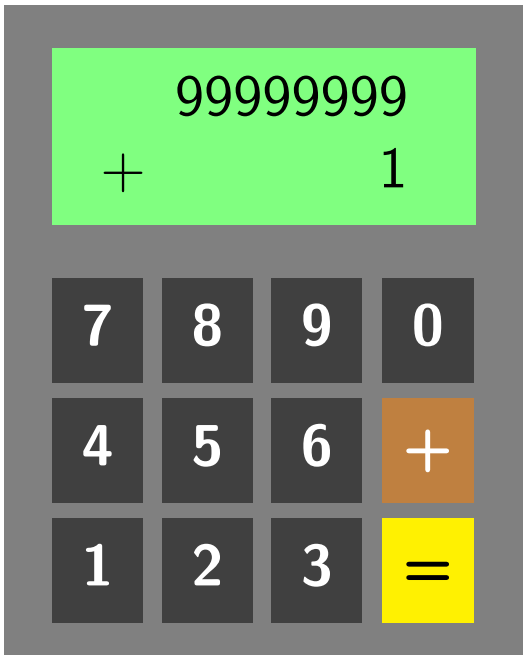

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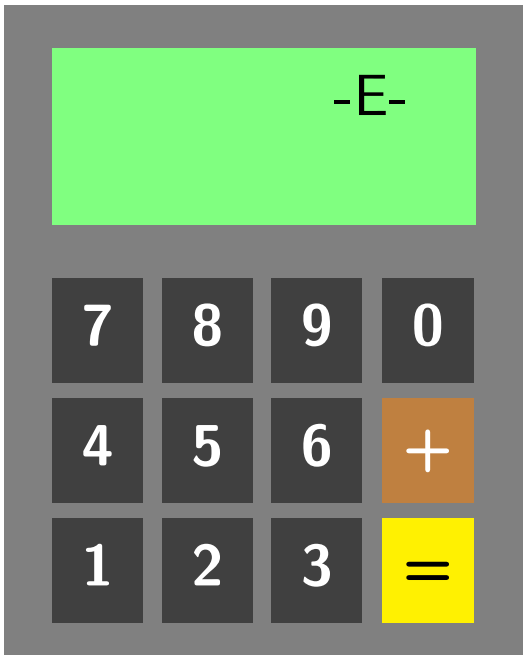

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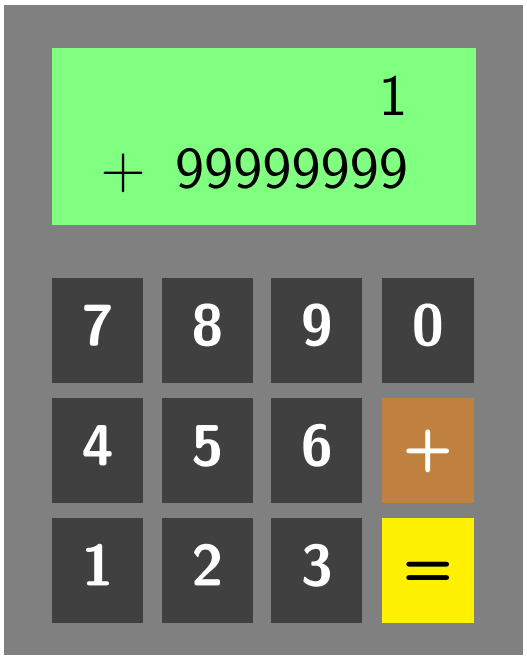

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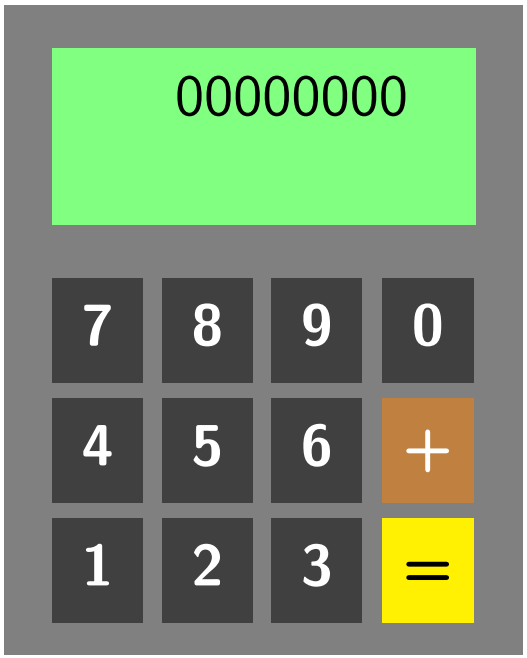

- Oops...

Behind the Scenes: Test $99999999 + 1$ *Failed...*

```
1  int add( int x, int y )
2  {
3    if (y == 1) // be fast
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6      return x+y;
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- **Programmer**: "Eh, piece of cake. ∗tippeditipp∗ Here you are!"
- **Tester**: "Fine, all tests passed!"

The Tests Revisited

With our test cases

- $27 + 1$,
- $13 + 27$,
- $12345 + 678$,
- $99999999 + 1$

we have

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- 100% statement coverage,

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and still didn't spot the bug.

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To be sure, we'd need to test all (how many?) combinations – **impractical**!

What If We Need to Be Sure?

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1  #define DIGIT_8_MAX 99999999
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3  int add( int x, int y )
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What If We Need to Be Sure?

(i) A precise (formal) specification:

- x and y are non-negative 8-digit numbers:
  $0 \leq x < 10^8$
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- all non-negative returned numbers are 8-digit:
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(ii) A representation of the specification understood by a verification tool.

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(iii) A verification tool:

```
% check add.c
line 19:  assertion violated
%
```

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What If We Need to Be Sure?

- Fix and check the fixed version:

```
% check add.c
verification succeeded
%
```

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- **Subject of the seminar!**

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- Alternative outcome:

```
% check add.c
out of memory
%
```

- None the wiser...

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Bottom Line: Formal Methods for C

A working definition for "formal methods for C":

(i) A precise, formal, mathematical **requirements specification**.

(ii) An algorithm which is able to **prove or disprove** for a given piece of C code whether it satisfies the specification.

(iii) At best: an implementation of that algorithm.

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- The tool may have bugs or run on buggy hardware.
- ...
- For production, the program may be compiled with a buggy compiler.
- ...

(Anticipated) Benefits

- **Increased confidence.**
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Possible motivations:

- **Loss of lives**: aerospace, railway, automotive, fire alarm, ...
- **Loss of health**: medical devices, ...
- **Loss of privacy**: encryption protocols, ...
- **Loss of money**: satellites, factory automation, ...
- ...

(Anticipated) Benefits

- **Increased confidence.**
- Sometimes **reduced overall costs**: "find errors early", despite **additional costs** for formalisation.

Possible motivations:

- **Loss of lives**: aerospace, railway, automotive, fire alarm, ...
- **Loss of health**: medical devices, ...
- **Loss of privacy**: encryption protocols, ...
- **Loss of money**: satellites, factory automation, ...
- ...

Errors sometimes already avoided by formalising requirements – e.g. "Heartbleed" could possibly have been avoided if RFC 6520 stated

> *A heartbeat protocol message is* **valid** *if and only if*
>
> $$\ldots \wedge \texttt{M.payload\_length} = \mathit{length}(\texttt{M.payload}) \wedge \ldots$$
>
> *Not* **valid** *messages MUST be discarded.*

The Seminar

Seminar...?

The Task

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- **Choose** a verification tool from the list (or propose your own).
- **Thread 1**: Literature research, what's the theory behind the tool?
- **Thread 2**: Get your hands dirty.
  - get acquainted with the tool on the VM ("Hi tool, nice to meet you!")
  - reproduce and understand the tool provider's favourite example(s)
  - show one more property in that example,
    find one more bug in that (possibly reasonably modified) example
  - see how the tool does on these three examples:
    - `scan_ushort()`
    - low battery monitor – programming task
    - a big example

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The Task

- **Attend** the 2-3 introductory lectures on C and formal methods basics.
- **Choose** a verification tool from the list (or propose your own).
- **Thread 1**: Literature research, what's the theory behind the tool?
- **Thread 2**: Get your hands dirty.
- **Present**: Block-Seminar, 30 min. (?) presentation with
  - tool name, brief history, etc.
  - what are the tool's capabilities?
  - what's the theory behind the tool?
  - how did the tool perform on the examples?
  - conclusion

  and participation in discussion after talk.

Formalia

Grade: $r \cdot b \cdot (0.3 \cdot S + 0.7 \cdot T)$

- $r \in \{0, 1\}$: repeatability package* (RP) for favourite example
- $b \in \{0, 1\}$: low battery monitor, not obviously broken
- $S \in \{1.0, \ldots, 4.0, 6.0\}$: talk structure
- $T \in \{1.0, \ldots, 4.0, 6.0\}$: presentation (incl. RP for three examples)

Deadlines:

- 30.6.2014: "theory behind the tool" part of the talk
- 14.7.2014: talk structure
- **tba**: presentation

*: shell script, Makefile, etc. which produces the results reported on in the talk by running the chosen verification tool on the examples with necessary parameters etc.

Talk Structure

- Formal Methods for C Kickoff
  - Introduction, ca. 10 Slides
  - Formal Methods, ca. 3 Slides
  - Formalia, ca. 3 Slides

Talk Structure

- Formal Methods for C Kickoff
  - Introduction, ca. 10 Slides
  - Formal Methods, ca. 3 Slides
  - Formalia, ca. 3 Slides

No.

Talk Structure Example

- Formal Methods for C Kickoff
  Goal: give sufficient information for semester planning regarding workload, i.e. sketch goals and content, fix requirements, discuss grading, agree on common language
  - Introduction (ca. 10 Slides)
    Goal: point out difference between testing and verification
    - little story on pocket calculator: show a bug which happens to be missed by tests
    - give example for a proper formal requirement on pocket calculator, say how verification would be used given the C code
  - Formal Methods (ca. 3 Slides)
    Goal: agree on common understanding of "formal methods", give outlook on motivation for their use and their limitations
    - working definition: formal requirements, prove/disprove algorithm, tool
    - limitations: e.g. bugs in checking tool
    - benefits: increased confidence, maybe lower overall cost
    - motivation: safety critical domain (transport, health, ...)
  - Formalia (ca. 3 Slides)
    Goal: agree on expected work, propose schedule and deadlines
    - firstly the C seminar, then choose a tool
    - then literature research and hands-on experience (two threads)
    - hands-on experience: tool's favourite example and three given ones
    - finally, block seminar; sketch expected content of talk
    - clarify "structure" using bad/good example

Plan Proposal

- check the VM and the homepage for the offered tools/topics
- decide until next week: favourite (and second best) topic

- now: decide for meeting time(s) for introductory lecture

- next meeting: assign topics (and supervisor)

References

[ISO, 1999] ISO (1999). Programming languages – C. Technical Report ISO/IEC 9899:1999, ISO. Second edition, 1999-12-01.