Formal Methods for Interactive Systems

Part 10 — Reverse Engineering with Matrix Algebra

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Reverse Engineering

Define a model of an existing device

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$\Longrightarrow$ formal specifications must be reconstructed

Reverse Engineering Process

Reconstruct formal specification from

- checking interaction results against the real device

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Reconstruct formal specification from

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- observing user-machine interaction in the real operating environemt
- interviewing real users and manifacturer
- checking documentation (e.g., user manual)

RE Advantages

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- case studies are more credible $\Longleftarrow$ not tailored for the used modelling / verification approach

Matrix Algebra

to describe interaction human-machine

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[Thimbleby 04]

Example: Pushbutton Switch

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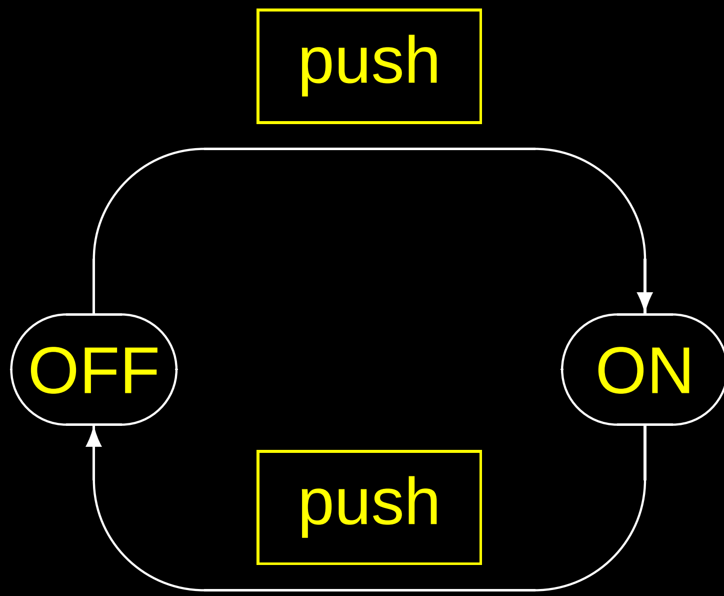
[Thimbleby 04]

Model of Pushbutton Switch



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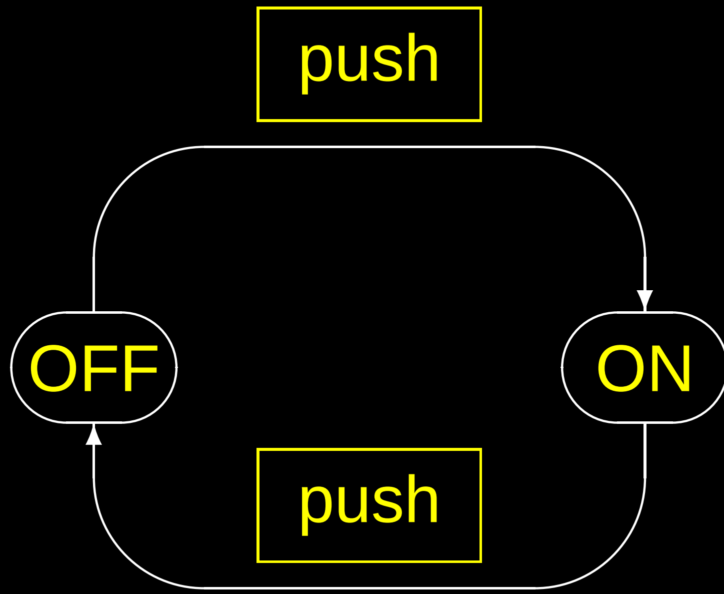

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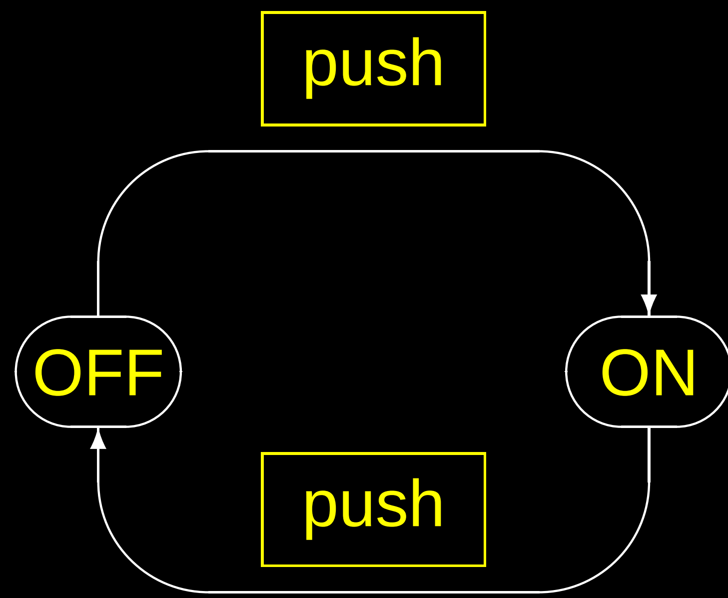

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Switch Safety

$$\text{OFF} \; \boxed{\quad \text{x} \quad} = \begin{bmatrix} 0 \;,\; 1 \end{bmatrix} \begin{bmatrix} x_{1,1} & x_{1,2} \\ x_{2,1} & x_{2,2} \end{bmatrix} = \begin{bmatrix} 0 \;,\; 1 \end{bmatrix} = \text{OFF}$$

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$$\exists\, n \quad \text{such that} \quad \boxed{\text{push}}^{\,n} = \boxed{\mathsf{x}} \ ?$$

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$$\begin{matrix} x_{1,1} = 0 & x_{1,2} = 1 \\ x_{2,1} = 0 & x_{2,2} = 1 \end{matrix} \implies \boxed{\text{x}} = \begin{bmatrix} 0 & 1 \\ 0 & 1 \end{bmatrix}$$

$\exists\, n$ such that $\boxed{\text{push}}^{n} = \boxed{\text{x}}$?

No because $\boxed{\text{push}}^{2} = I$

Safer System

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$$\text{ON}\ \boxed{\quad \text{y} \quad} = \begin{bmatrix} 1 & , & 0 \end{bmatrix} \begin{bmatrix} y_{1,1} & y_{1,2} \\ y_{2,1} & y_{2,2} \end{bmatrix} = \begin{bmatrix} 0 & , & 1 \end{bmatrix} = \text{OFF}$$

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$$x_{2,1} = 1 \quad x_{2,2} = 0 \qquad \Longrightarrow \qquad \boxed{\quad x \quad} = \begin{bmatrix} - & - \\ 1 & 0 \end{bmatrix}$$

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$$x_{2,1} = 1 \quad x_{2,2} = 0 \quad \Longrightarrow \quad \boxed{\quad \text{x} \quad} = \begin{bmatrix} 1 & 0 \\ 1 & 0 \end{bmatrix} = \boxed{\quad \text{on} \quad}$$

$$y_{1,1} = 0 \quad y_{1,2} = 1 \quad \Longrightarrow \quad \boxed{\quad \text{y} \quad} = \begin{bmatrix} 0 & 1 \\ 0 & 1 \end{bmatrix} = \boxed{\quad \text{off} \quad}$$

Two-position Switch

A ligh bulb controlled by a two-position switch

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One switch position (on) turns the light on; the other (off) turns the light off.

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Properties

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Properties

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- any sequence of actions is equivalent to the last actions the user does

Remarks

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- direct manipulation of matrices (operations) rather than vectors (states)
  $\Longleftarrow$ number of operations much smaller than number of states
- the methodology is
  - scalable
  - mechanisable [Gow and Thimbleby 04]

Calculator

- Model: CASIO HL-820LC

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- State
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- Operations: binary 2×2 matrices

Calculator Functions

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- $\boxed{\text{MRC}}$ $\boxed{\text{MRC}}$ recall and clear memory

MRC

What is the precise semantics of MRC?

- pressed once

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- pressed twice
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Remarks on MRC

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- Is $\boxed{\text{MRC}}(\ \boxed{\text{MRC}}\ \boxed{\text{MRC}}\ ) = (\ \boxed{\text{MRC}}\ \boxed{\text{MRC}}\ )\ \boxed{\text{MRC}}$?
- Calculator:
  $\boxed{\text{MRC}}\ (\ \boxed{\text{MRC}}\ \boxed{\text{MRC}}\ ) = \boxed{\text{MRC}}\ \boxed{\text{MRC}}$

Bad Design?

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Bad Design?

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- No!
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- $\boxed{\text{MRC}}$ $\boxed{\text{MRC}}$ is a bad design choice!

[Thimbleby 00]

Safety-critical

- Is a calculator safety-critical?

Safety-critical

- Is a calculator safety-critical?
- May a calculator-like interface be safety-critical?

Safety-critical

- Is a calculator safety-critical?
- May a calculator-like interface be safety-critical?
- Yes!
  Syringe pump have calculator-like interfaces

Examinations

Seminar 6 — Usable Calculator

Topic: Calculator Interfaces

Towards a truly usable calculator

- Harold Thimbleby
  Computer Algebra for User Interface Design, 2004
- Harold Thimbleby
  A Novel Pen-based Calculator and its Evaluation, 2004
- Will Thimbleby and Harold Thimbleby
  A Novel Gesture-based Calculator and its Design Principles, 2005
- Websites on
  - Computer Algebra: http://www.cs.swan.ac.uk/~csharold/CA/
  - Calculator: http://www.cs.swan.ac.uk/calculators/

References

Reverse Engineering

- [Thimbleby 04]: Reverse Engineering and Matrix Algebra
- [Gow and Thimbleby 2004]: Matrix Algebra and Tools
- [Thimbleby 00]: Reverse Engineering

[Thimbleby 04]

Harold Thimbleby.
User interface design with matrix algebra.
ACM Transactions on Computer-Human Interaction, Vol. 11, No. 2, 2004, pages 181–236.

About:

- Reverse Engineering
- Matrix Algebra

[Gow and Thimbleby 04]

Jeremy Gow and Harold Thimbleby.
MAUI: An Interface Design Tool Based on Matrix Algebra.
In *Proceedings of CADUI 2004*, Springer, 2004, pages 81–94.

About:

- Tools

[Thimbleby 00]

Harold Thimbleby.
Calculators are needlessly bad.
International Journal of Computer-Human Studies, Vol. 52, No. 6, 2000, pages 1031–1069.

About:

- Reverse Engineering of Calculatos