Well-formed Dependency and Open-loop Safety

Based on Slides by Professor Lui Sha

Reminders and Announcements

- Announcements:
  - CS 424 is now on Piazza:

    piazza.com/illinois/fall2017/cs424/home
  - We must form 4-person groups for robot-based MPs (each group gets one robot)
    - If you already formed a group, please send me and Yiran Zhao (the TA) the names of your group partners (email to: zhao97@illinois.edu, with CC: zaher@Illinois.edu). Please use the subject: “CS424 GROUP” (in upper case).
    - All people who do not have a group by the end of next week will be assigned a group by us.

Recap

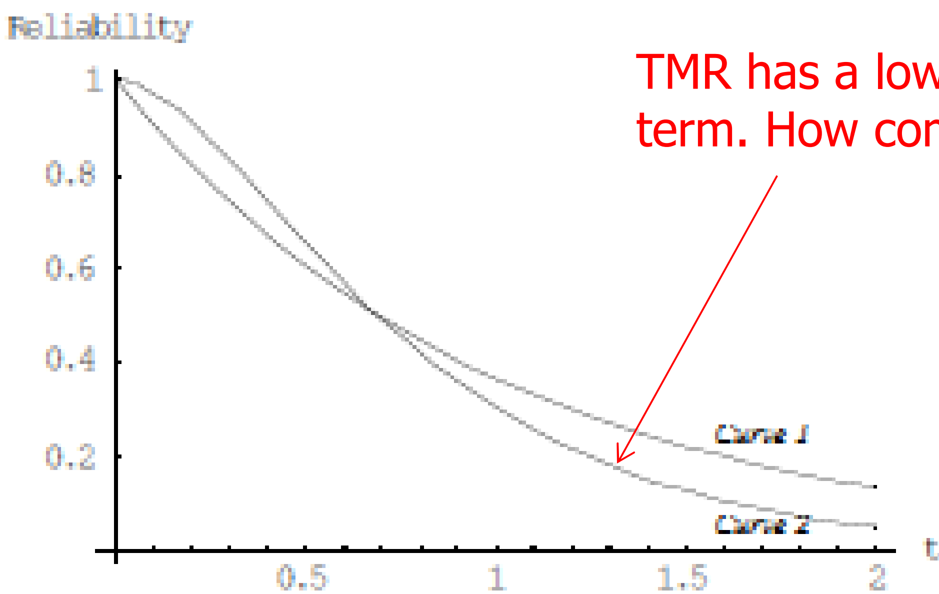
- Reliability for a giving mission duration t, $R(t)$, is the probability of the system working as specified (i.e., probability of no failures) for a duration that is at least as long as t.
- The most commonly used reliability function is the exponential reliability function:

$$R(t) = e^{-\lambda t}$$

where λ is the failure rate.

Triple Modular Redundancy

- Which case is TMR?



TMR has a lower reliability in the long term. How come?

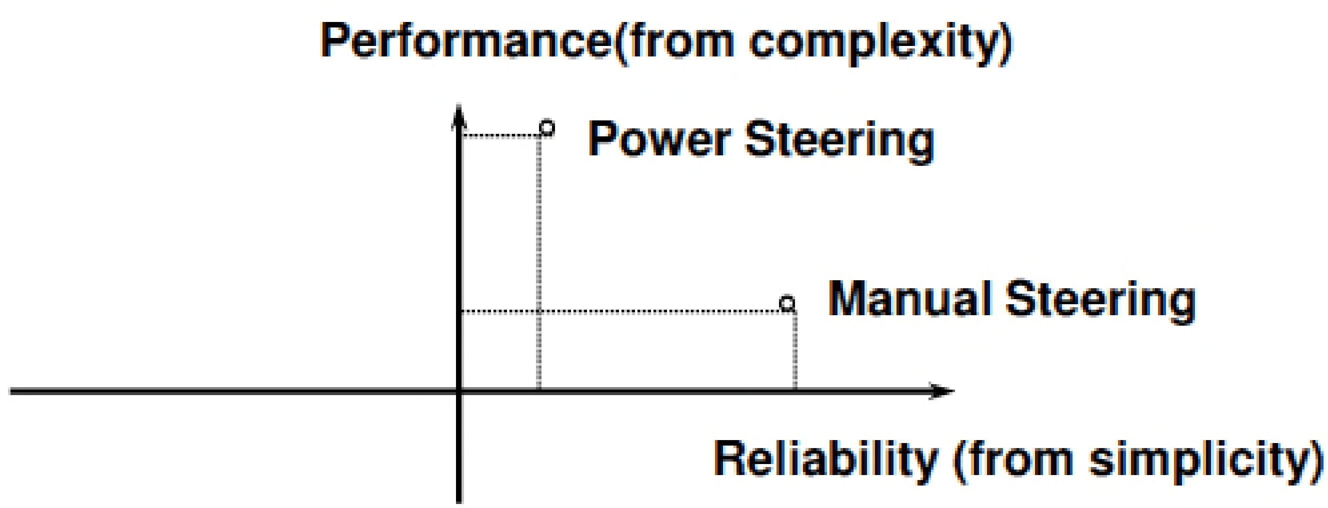
Implications of the Postulates

$$R(Effort, Complexity, t) = e^{-kC\,t/E}$$

- Note: splitting the effort greatly reduces reliability.

Analytic Redundancy and Complexity Reduction

- Partial redundancy via simple backup that meets only safety-critical requirements



Example: A Sorting Exercise

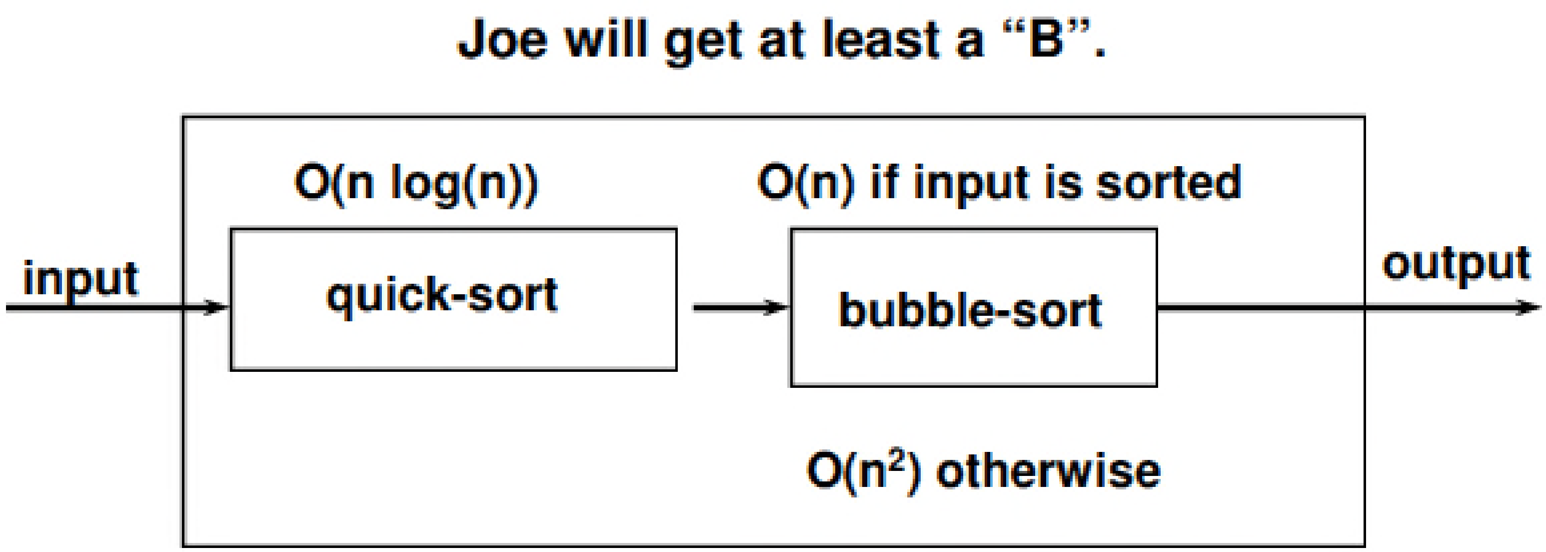
- Sorting:
  - Bubble sort: easy to write but slower, $O(n^2)$
  - Quick sort: faster, $O(n \log(n))$, but more complicated to write
- Joe remembers how to do bubble sort, but is not perfectly sure of quick sort (has a 50% chance of getting it right).
- Joe is asked to write a sorting routine:
  - Correct and fast: A
  - Correct but slow: B
  - Incorrect: F

What is Joe's optimal strategy?

Critical requirement:
Must pass!

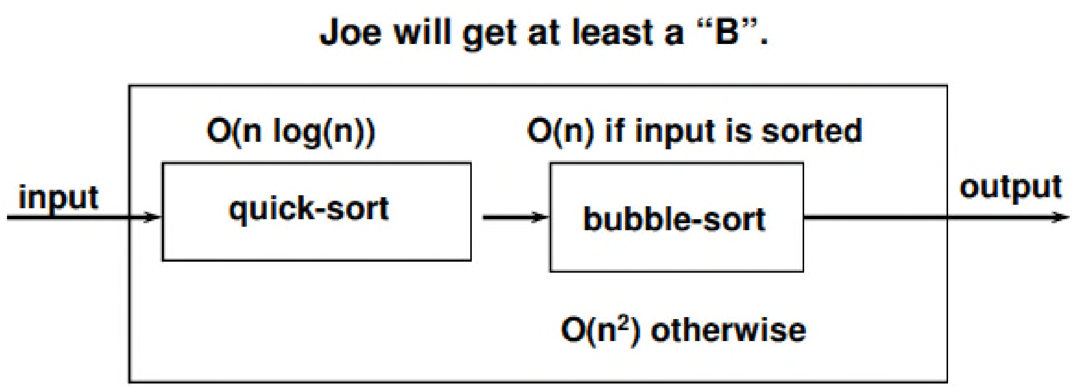
Solution

- Simplicity to "control" complexity



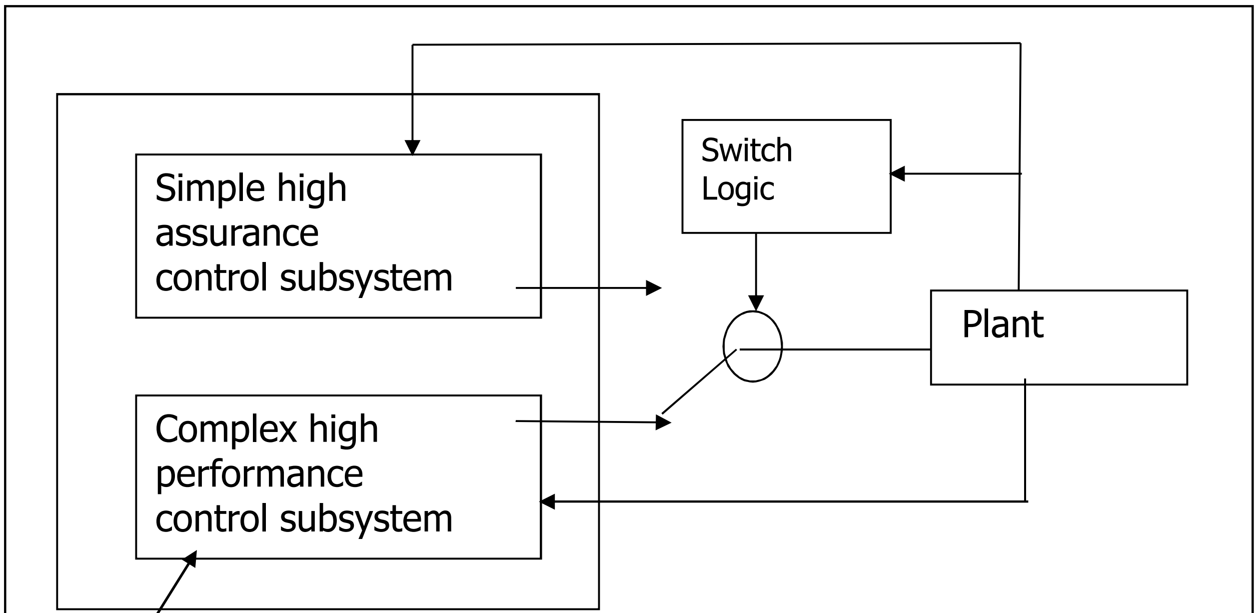
Solution

- Key property
  - Use complex but efficient solution in the common case
  - If the complex solution fails, catch the failure and switch to the simple (less efficient) but safe option



Simplex Architectural Pattern

A simple verifiable core; diversity in the form of 2 alternatives; feedback control of the software execution.



Data Flow Block Diagram

Better performance, but less reliable

Example

- Component with mean time to failure = 10 years. Compare the reliability of:
  a) Using this component alone
  b) TMR using three versions of this component

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  Answer:

  a) $r(t) = e^{-\lambda t} = e^{-(1/10).1} = 0.9048$

  b) $r(t)^3 + 3r(t)^2 (1 - r(t)) = 0.9745$

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After 15 years

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  After 15 years

  Answer:

  a) $r(t) = e^{-\lambda t} = e^{-(1/10).15} = 0.2231$

  b) $r(t)^3 + 3r(t)^2 (1 - r(t)) = 0.1271$

Example

- Component with mean time to failure = 10 years. Compare the reliability of:
  a) Using this component alone
  b) TMR using three versions of this component
  c) Using this component with a reduced complexity backup (C = 0.1)

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  - a) Using this component alone
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  - c) Using this component with a reduced complexity backup (C = 0.1)

  After 15 years

  Answer:

  c) $r_1(t) = e^{-\lambda t} = 0.2231$, $r_b(t) = e^{-0.1\lambda t} = 0.8607$

Example

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  - a) Using this component alone
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After 15 years

Answer:

c) $r_1(t) = e^{-\lambda t} = 0.2231$, $r_b(t) = e^{-0.1\lambda t} = 0.8607$

$1 - (1 - r_1(t))(1 - r_b(t)) =$ 0.8918

Example

- Component with mean time to failure = 10 years (at unit complexity and unit budget). Compare the reliability of:
  - a) Using this component alone
  - b) TMR using three versions of this component assuming same total budget

After 1 year

Example

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Example

- Component with mean time to failure = 10 years (at unit complexity and unit budget). Compare the reliability of:
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After 1 year

Answer:

a) $r(t) = e^{-\lambda t} = e^{-(1/10).1} = 0.9048$

b) $r_2(t) = e^{-3 \lambda t} = 0.7408$

$r_2(t)^3 + 3r_2(t)^2 (1 - r_2(t)) = 0.8333$

Lessons Learned?

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- More components/redundancy is not always better
- When budget is finite, more components means "spreading thinner" → lower reliability
- Having a simple (i.e., low complexity) back-up significantly improves reliability!

Well Formed Dependencies

- *Informal intuition:* A reliable component should not *depend* on a less reliable component (it defeats the purpose).

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- Design guideline: **Use but do not depend** on less reliable components

Well Formed Dependencies

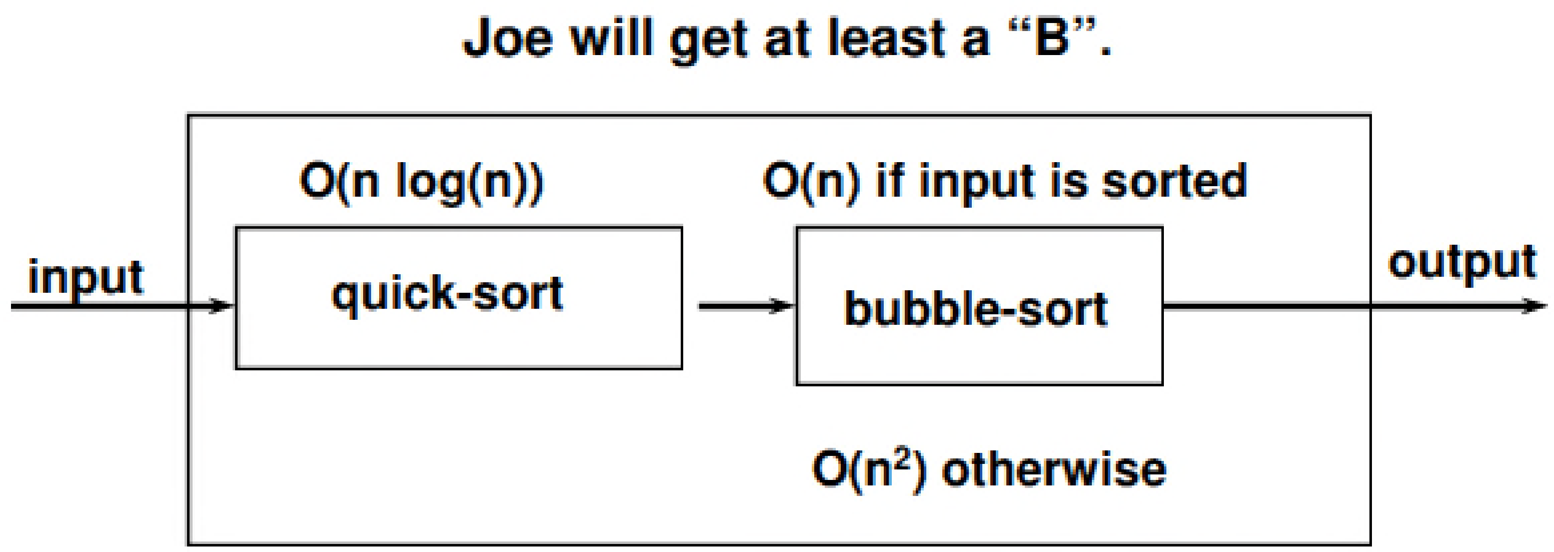
- Component A is said to depend on B, if the correctness of A's service depends on B's correctness.
- Component A is said to *use* the service of B, but not depend on it for its critical service S, if S can function correctly in spite of all B's faults.
- A system's dependency relations are said to be well-formed if and only if critical components may *use but do not depend* on the less critical components

Design Philosophy

- Build the system out of a reliable core and less reliable components
- Ensure that the reliable core is *minimal* (must be simple to reduce complexity – see lessons learned from reliability examples)
- The reliable core can use but do not depend on other components (i.e., failures elsewhere should not affect reliable core)
- The reliable core should ensure safety or recover from failures of other components

Sorting Revisited

- How does the reliable component depend on the less reliable component? How to fix it?



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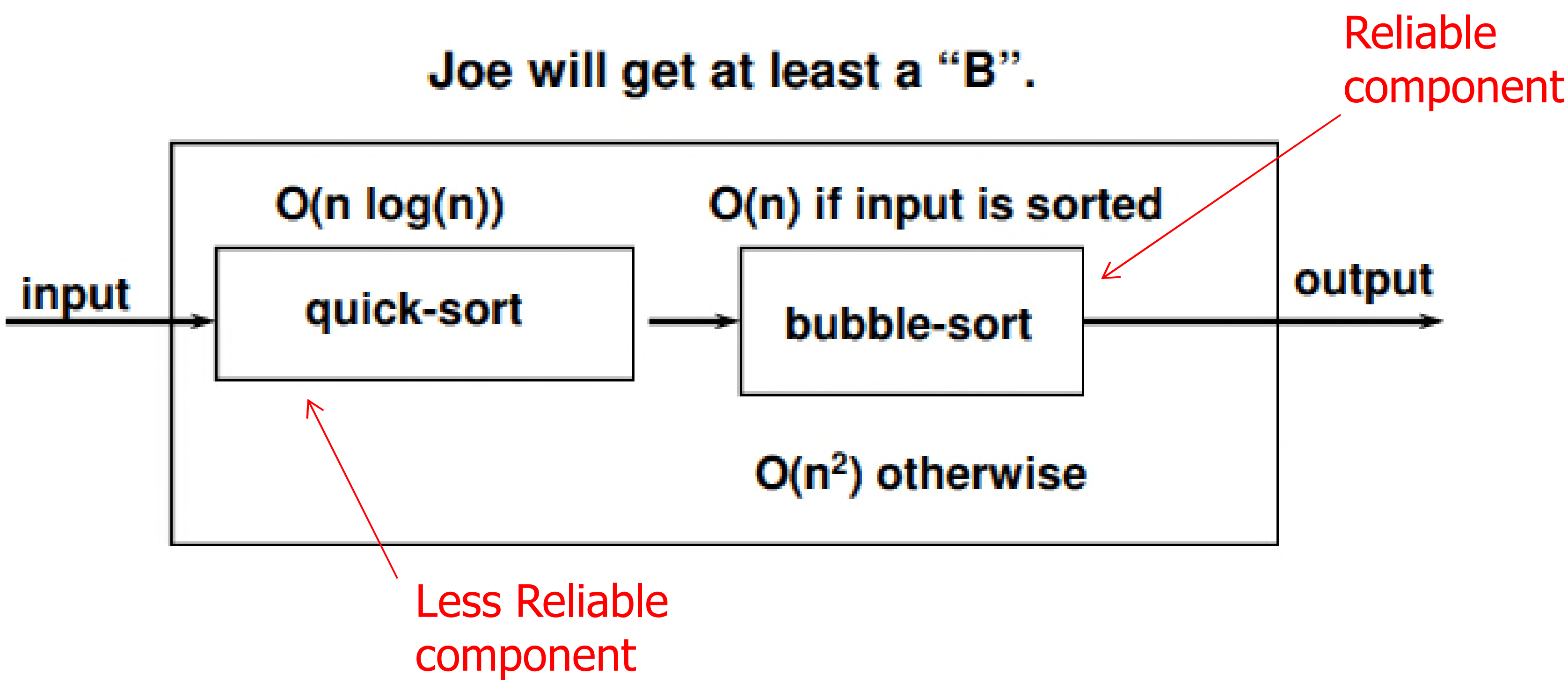

Sorting Revisited
Ensuring Well-formed Dependencies

- Resource sharing faults
  - Memory accessing fault: address space isolation
  - Hogging the CPU: CPU cycle limit
  - Timing fault: time out.
- Semantic fault
  - Wrong order: Bubble sort
  - Corrupt the input data item list: Export only a permutation function on a protected input list

Safe State

- In cyber-physical systems it important to keep the system from harm. The reliable core must ensure that the system remains in a safe state (keep the kid away from the freeway!!) even when other components fail
- Example:
  - If your tire blows up, safely park the car on the shoulder of the road (safe state)

Discussion: Patient Controlled Analgesia

- When pain is severe in a post-surgery patient, the patient can push a button to get more pain medication (morphine: drug overdose will cause death). This is an example of a lethal device in the hands of an error-prone operator (the patient). How can we ensure safety of software controlled PCA?