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Distributed Information Processing

What's Ahead for Embedded Software?

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(2013-20742)

2015-11-17

Outline

- Introduction
- Frameworks
- HW-SW Partnership
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- Interfaces and Types
- Metaframeworks
- Conclusion

Introduction

- **What is *Embedded Software* ?**
  - ✓ The software which engages the physical world
    by interacting directly with sensors and actuators.
    - Which has taken over what mechanical & dedicated electronic systems used to do.
  - ✓ ex. telephones, pagers, systems for medical diagnostics and climate control

- **Why *Embedded Software* research now?**
  - ✓ Once deemed too small and retro for research

    ↓

  - ✓ Grown complex and pervasive enough to attract the computer scientists

Introduction

- **Research issue about embedded software**
  - ***<u>"How to reconcile a set of domain-specific requirements with the demands of interaction in the physical world"</u>***
  - ***<u>"How do you adapt software abstractions to meet the requirements?"</u>***
    - Real-time constraints
    - Concurrency
    - Stringent safety considerations
  - The answer to the question has given rise to some promising research angles.

Frameworks

- **Component**
  - ✓ Any kind of building block
  - ✓ ex. set of functions, modules, subroutines

- **Framework**
  - ✓ A set of constraints on components and their interaction
  - ✓ A set of benefits that derive from those constraints
  - ✓ Defines a model of computation, which governs the interaction of components

- **The first step in understanding suitable models of computation is to understand what makes a framework useful for embedded system design.**

Frameworks

- **Most frameworks have four service categories:**
  - Ontology: what it means to be a component
    - ex. subroutine, state transformation, process, object
  - Epistemology: state of knowledge
    - ex. sharing information, scoping rules, connectivity
  - Protocols: how components interact
    - ex. rendezvous, semaphores, monitors, timed events
  - Lexicon: vocabulary of component interaction
    - ex. type system

Frameworks

- **A framework may be very broad or very specific**
  - ✓ The more constraints, the more specificity
  - ✓ The more specificity, the more benefits
  - ✓ Examples
    - UNIX pipe: Not support feedback structre, but no deadlock
    - Internet: Constraints on lexicon (byte stream), protocol (HTTP), but provides platform independence
- **KEY: “To invent framework that better match the application domain”**
  - ✓ Requirements
    - Reintroduction of time
    - Recongize of essential properties when components become an aggregate

Frameworks

Concurrency

- A framework with concurrency can perform some computation in parallel.
  - However, concurrency also seriously complicate system design.

Examples for concurrency

- Von Neumann framework
  - A universally accepted model of sequential computation
  - It reduces time to a total order of discrete events for correctness

- Distributed systems
  - Maintaining such a total order globally is expensive
  - Events are partially ordered at best.
  - This partial ordering makes it difficult to maintain a 'global system state'.

Frameworks

- **Sample frameworks**
  - ✓ So far, most designers are exposed to only one or two frameworks.
  - ✓ But, design practices has changed
    -the level of abstraction and domain specificity rise-
  - ✓ The diversity will make it hard to select a framework.
    -Designers need some way to reconcile the views-
  - ✓ Example answer: Different views for ‘Time’
    - Explicitly: as a reaul number
    - Abstractly: as a discrete number

Frameworks

- **Mixing frameworks**
  - A grand unified approach to modeling would seek
    a concurrent framework that serves all purposes.

  - Possible approaches
    - To create the union of all the frameowrks

    : Complex and hard to use (+Design would be difficult)

    - To choose one concurrent framework and
      show that all the others are special cases of that

    : Relaytively easy to use
    but it dosen’t acknowledge each model’s strengths and weaknesses

    - To use an Architecture Description Language (ADL)

    : Describe the component interactions
    It provides a good insights into the design, and sometimes it gives poor match.

    - To heterogeneously mix frameworks, preserving their distinct identity

HW-SW Partnership

- **Since 1970, functionality has steadily shifted from HW to SW.**

- **Software**
  - ✓ Primarily sequential execution with a single instruction stream
  - ✓ HW resources are multiplexed in time to perfrom a variety of fucntions.

- **Hardware**
  - ✓ Primarily parallel execution
  - ✓ HW resources are not shared. (or at least, not as much)

- **Most embedded systems involve both HW and SW design, a designer's task is to explore the balance between the two styles.**

HW-SW Partnership

- **For hard-real-time functions (i.e., signal processing), designers often assign concurrent tasks to distinct processors.**
  - ✓ ex. the speech coders and radio modems in a digital cellular telephone

- **In theory, as embedded processor improves, there should be less need for such HW specialization.**
  - ✓ Until then, designers must use dedicated HW or use processors that so greatly exceed minimum performance.

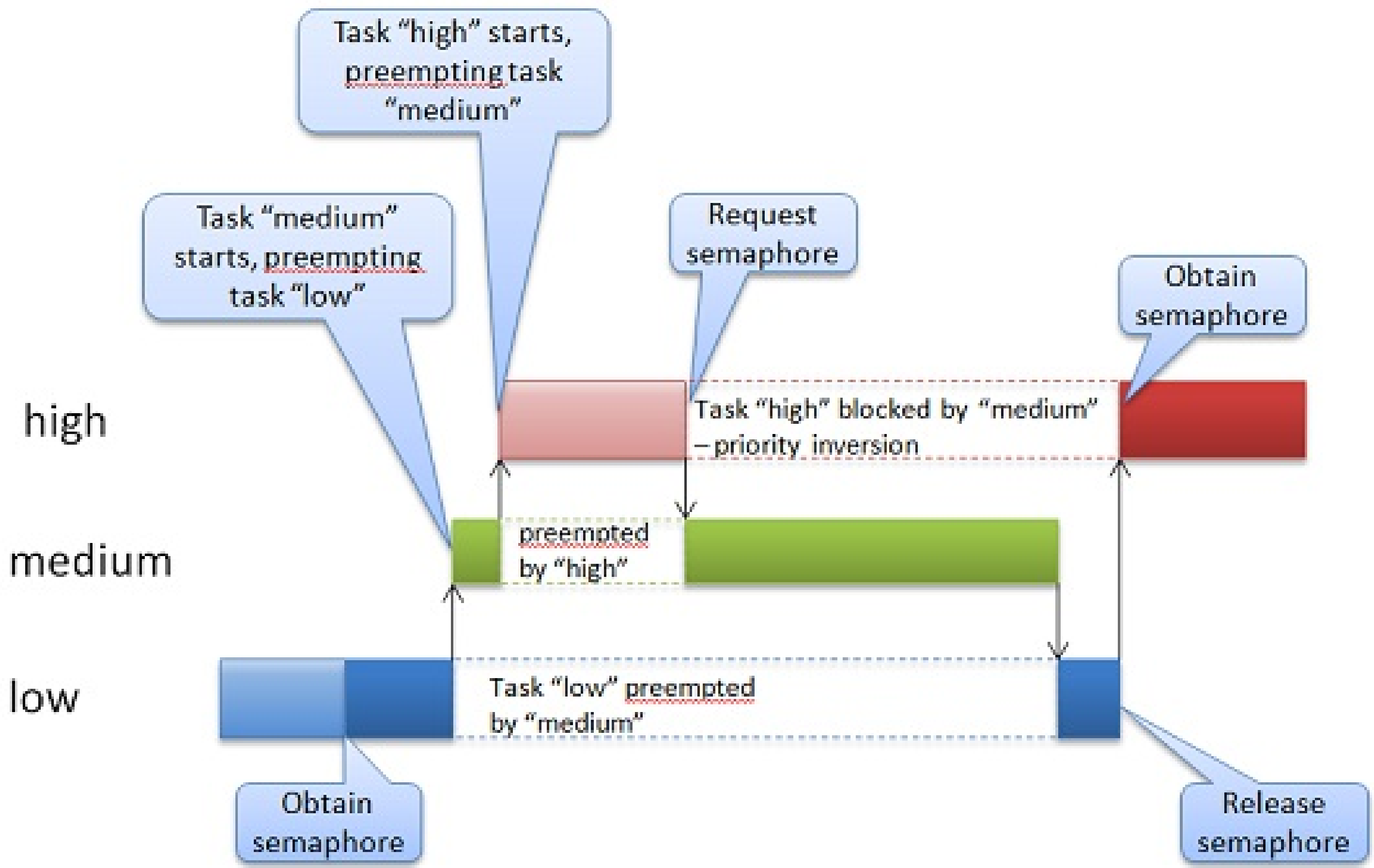
- **However, Real-Time OSs cannot yet reliably handle many hard-real-time tasks.**
  - ✓ The embedded system community must rethink multitasking.
    - Component interface need to declare temporal properties, not just a fixed priority.
    - Compositions of components must have consistent and non-conflicting temporal properties.

Real-Time Scheduling

- **Real-time scheduler**
  - It provides assurance of timely performance given certain component properties.
  - ex. A component ‘s invocation period or task deadlines
- **Rate-monotonic scheduling principle**
  - It translates the invocation period into priorities.
  - Priorities may also be based on semantic information about the application.
- **Problem: most methods are not compositional.**
  - A method can provide assurances individually to each component.
  - There is no systematic way to provide assurance for the aggregate of the two or more components.
  - ex. priority inversion

Real-Time Scheduling

- **Priority Inversion**
  - ✓
  - ✓ rces)



Interfaces and Types

- **Type systems**
  - One of the great practical triumphs of contemporary software.
  - Ensure correctness of software
  - Provide a vocabulary for talking about larger structure

- **Disadvantage for embedded software**
  - Type systems talk only about static structure
    -the syntax of procedural programs
  - There is nothing about the program's concurrency or dynamics.
  - Work with active objects and actors moves a bit in the right direction
    - But it does not say enough about interfaces to ensure safety, liveness, consistency or real-time behavior

Interfaces and Types

- **Type system technique**
  - ✓ Type system constraints
    - What a component can say about its interface
    - How to ensure compatibility
  - ✓ How a type system works
    - Data-level type system

    : subtyping relation or lossless convertibility

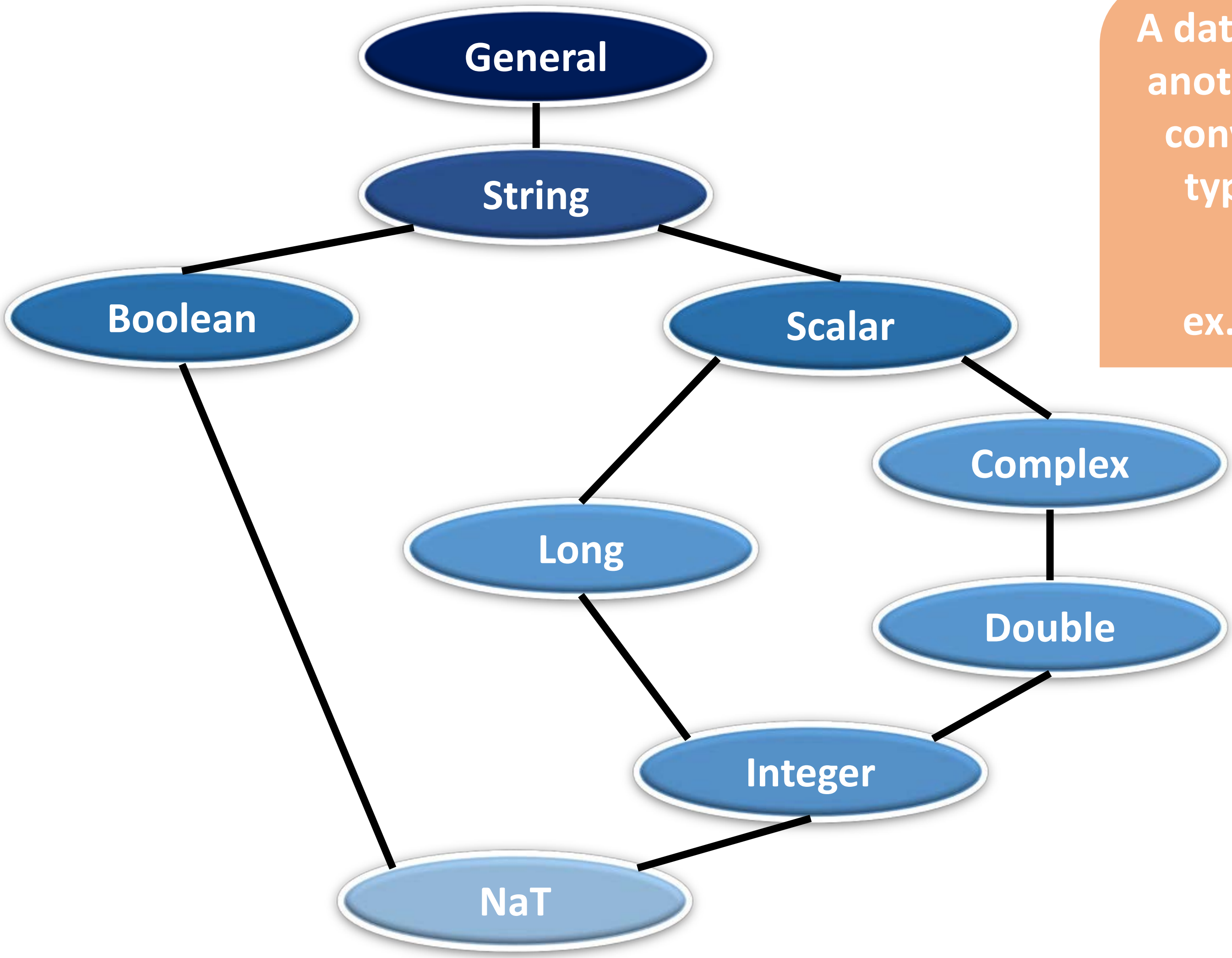
    - System-level type system

    : dynamic properties using non-deterministic automata

    –A type is less than another if the other simulates first

Interfaces and Types

- How a type system works: Data-level type

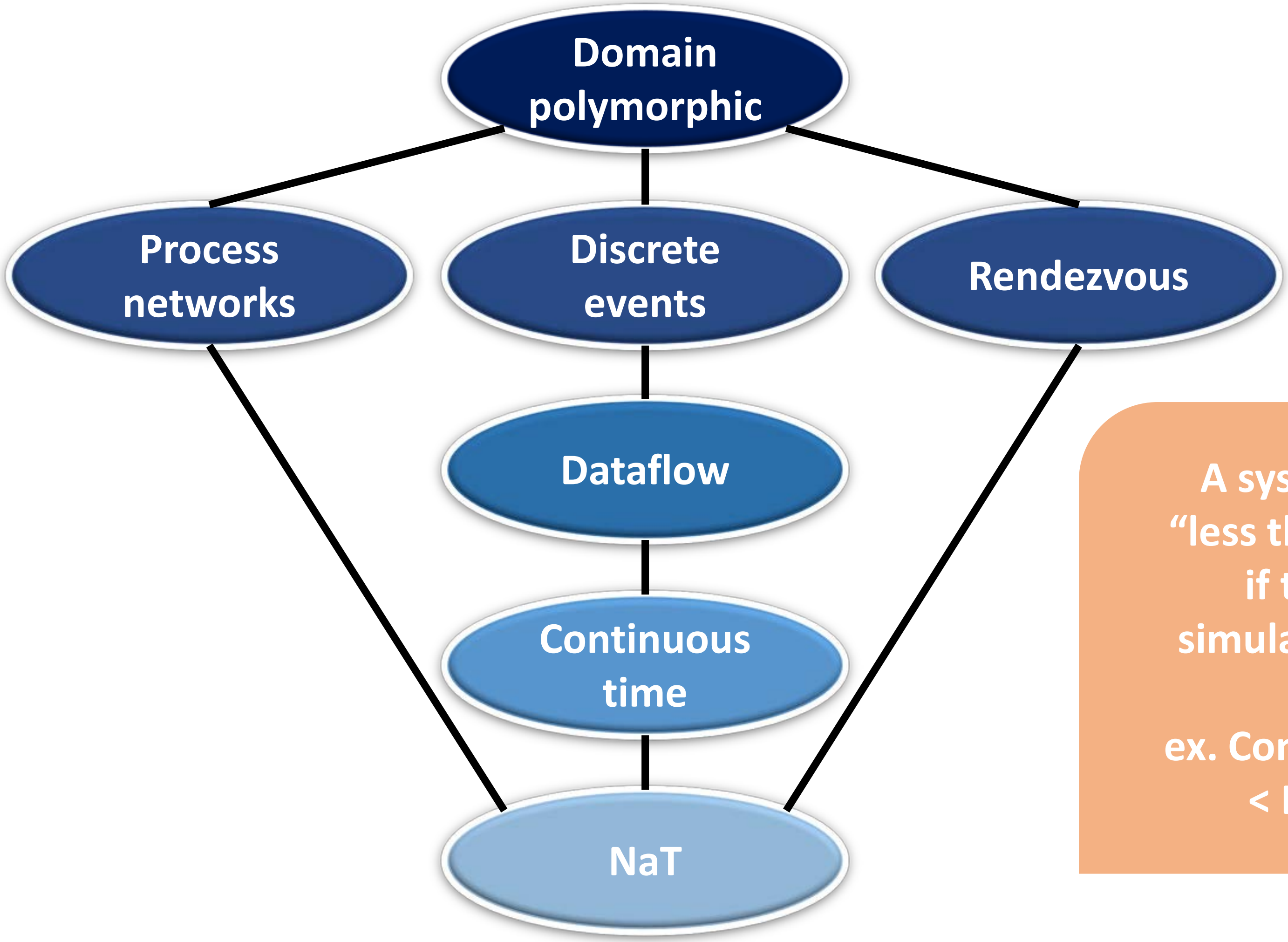


A data type is “less than” another type if it can be converted to the other type without loss of information.

ex. Integer < Double

Interfaces and Types

- How a type system works: System-level type



A system type is "less than" another if the other simulates the first.

ex. Continuous time < Dataflow

Interfaces and Types

- **The case for strong typing**
  - Strongly typed languages (i.e., Java, ML)
    - Emphasize catching error ASAP-often the compiler catches them
    - Vulnerable to other programming errors

    ex. accessing an array out of bounds
    - Compromise modularity and discourages reuse
  - Languages without strong typing (i.e., Lisp, Tcl)
    - Emphasize modularity and reusability
    - Difficult to identify the source of the problems and guaranteeing the code may be impossible
  - For embedded systems, the extra degree of safety that strong typing offers overwhelms even the desire for modularity and reuse.
    - The question then becomes how to achieve modularity and reuse without discarding strong typing.

➡ to use polymorphism, reflection, and runtime type inference and type checking

Metaframeworks

- **Stronger benefits come at the expense of stronger constraints.**
  - Frameworks become rather specialized as they seek these benefits.
  - Drawback
    : They are unlikely to solve all the framework problem for any complex system.
- **To avoid giving up the benefits of specialized frameworks, designers will have to mix frameworks heterogeneously.**
  - Through specialization (= subtyping)
  - To mix frameworks hierarchically
  - Examples
    - Ptolemy project at UC Berkeley
    - The gravity system and its visual editor Orbit

Conclusion

- **We have studied some interesting embedded system research problems.**

- **The author has focused on constructing embedded software, since it become a first-class of programming exercise.**
  - ✓ Embedded system designers need more!

- **The focus must move beyond a program's functional correctness to its temporal correctness.**

- **The key problem then becomes identifying the appropriate abstractions for representing the deisgn.**