T2

What the Second Generation Holds

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In the Beginning

(1999)

- Sensor networks are on the horizon...
- ... but what are they going to do?
  - What problems will be important?
  - What will communication look like?
  - What will hardware platforms look like?
- Having an operating system is nice...
- ... but how do you design one with these uncertainties?

The TinyOS Goals

(ASPLOS 2000)

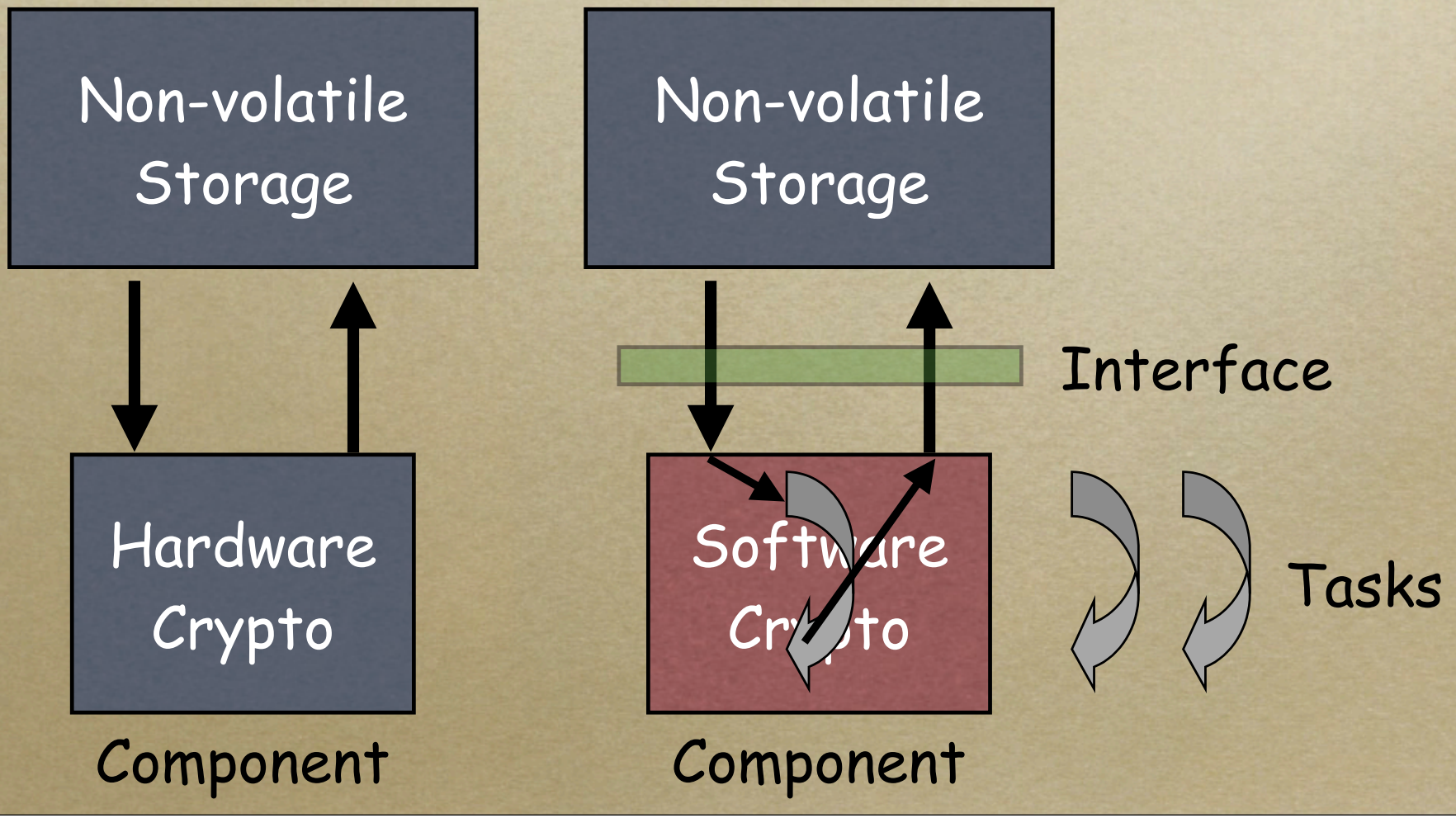
- Allow high concurrency
- Operate with limited resources
- Adapt to hardware evolution
- Support a wide range of applications
- Be robust
- Support a diverse set of platforms

TinyOS Basics

- A program is a set of components
  - Components can be easily developed and reused
    - Adaptable to many application domains
  - Components can be easily replaced
  - Components can be hardware or software
    - Allows boundaries to change unknown to programmer
- Hardware has internal concurrency
  - Software needs to be able to have it as well
- Hardware is non-blocking
  - Software needs to be so as well

TinyOS Basics, Continued

(2002)



The TinyOS Goals

(ASPLOS 2000)

- Allow high concurrency
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The TinyOS Goals

(The David Gay Scorecard, 2005)

- Allow high concurrency (A)
- Operate with limited resources (A-)
- Adapt to hardware evolution (B)
- Support a wide range of applications (B)
- Be robust (C)
- Support a diverse set of platforms (D)

The T2 Agenda

- Allow high concurrency (A)
- Operate with limited resources (A–)
- Adapt to hardware evolution (B)
- Support a wide range of applications (B)
- Be robust (C)
- Support a diverse set of platforms (D)

Outline

- TinyOS
- Issues facing a second-generation OS
- T2 core structure
- Multi-layer abstractions
- Static binding and allocation
- Service distributions

The Issues Ahead

- Support a wide range of applications (B)
  - Building small applications is easy
  - Building large applications is possible, but hard
- Be robust (C, but a D in Phil's world)
  - New hardware has punched holes in assumptions
  - Many unforeseen interactions
- Support a diverse set of platforms (D)
  - Current trend is to have 1-2 supported platforms
  - More platforms leads to lots of redundant code

Diverse Platforms

- Problem: many new platforms emerging, but few run TinyOS
  - E.g., “How do I port TinyOS to my new platform with an XXX?”
  - E.g.,“Porting TinyOS requires a lot of work!”
- Cause: platforms are self-contained units, with dependencies and assumptions

Future Platforms

- A platform is usually a collection of interconnected hardware chips

Platform	MCU	Radio
mica2	ATMega128	CC1000
micaZ	ATMega128	CC2420
Telos	MSP430	CC2420
eyes	MSP430	Infineon

- A next generation OS needs to separate the code for hardware resources from the code that composes them into a platform.

Robustness

- Problem: failures of structure
  - Components written to operate independently, but manifest conflicts when combined
  - E.g., “The ADC hangs when I send packets!”
- Problem: failures of abstraction
  - Dynamic allocation leads to dynamic failures
  - Generally, TinyOS follows a static allocation policy, except for one place: the task scheduler
- Cause: TinyOS didn’t get everything right the first time

Improving Robustness

- A next generation OS needs to define a structure and architecture for how components interact
  - Mechanisms and division of responsibilities
- A next generation OS needs to identify and redefine problematic abstractions
  - There's a five years of experience from thousands of users

Application Support

- Problem: building large applications out of many independent components is hard
  - E.g., “Why is it that if I turn off the radio to save power, flash storage stops working?”
  - E.g., “Why is it that if I put the send queue above this component it hangs?”
- Problem: inefficiency of defensive code
  - E.g., the radio stack is initialized 6 times
- Cause: components are independent, applications are not

Supporting Applications

- Complexities stem from hidden dependencies over shared resources
  - E.g., SPI bus
- Inefficiencies stem from tension between local independence and global properties
  - All 6 use the radio, but how can the app know?
- A next generation OS needs to have true APIs that encapsulate underlying services in a usable whole

An Example: CC2420

- Platform diversity: needs to be easily portable to new platforms (micaZ + Telos)
- Robustness: 1.x implementation breaks TinyOS concurrency model due to shared task queue
- Applications: interactions with other components are a big source of problems

Three Approaches

- Multi-layer abstractions
  - Present a true spectrum of abstraction layers, from the most general and portable to the most efficient and platform-specific
- Static binding and allocation
  - Anything and everything that can be determined statically, should be
- Service distributions
  - A coherent collection of APIs above the OS core, which implement policies for an intended set of application domains

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T2 Core

- Platforms
- Concurrency model
- Scheduler

T2 Platforms

- A platform is a collection of chips

Platform	MCU	Radio
mica2	ATMega128	CC1000
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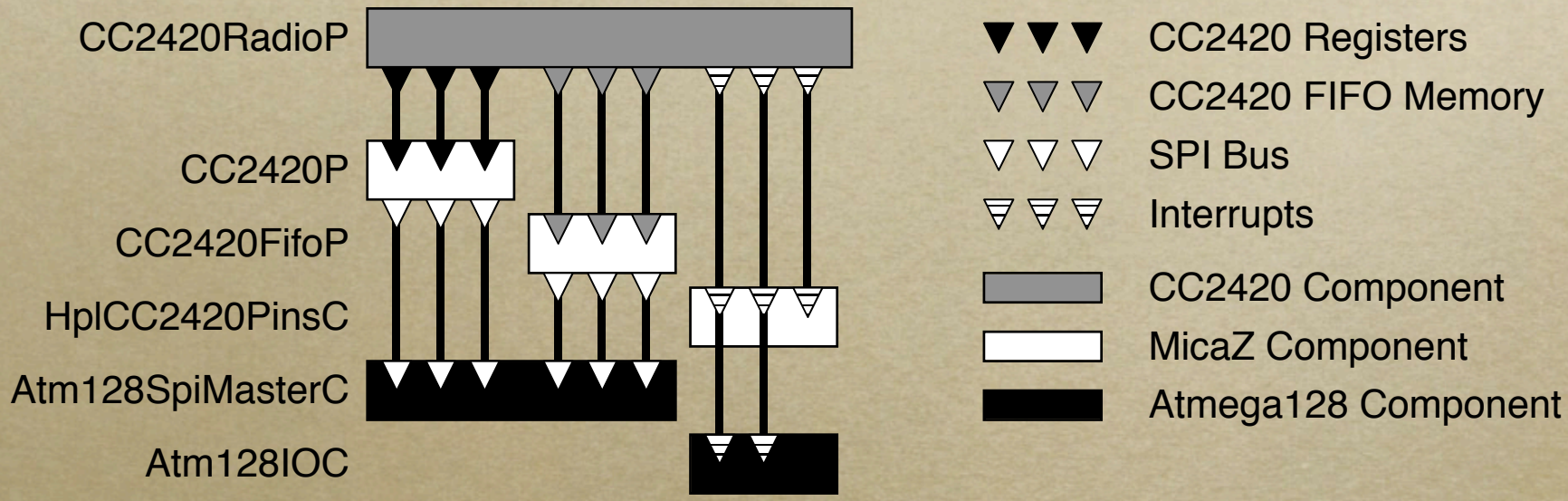
- Chip implementations are platform independent
- Platforms provide adapter code

Example: CC2420

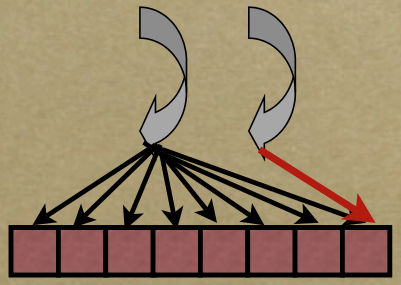


TinyOS 1.x Concurrency

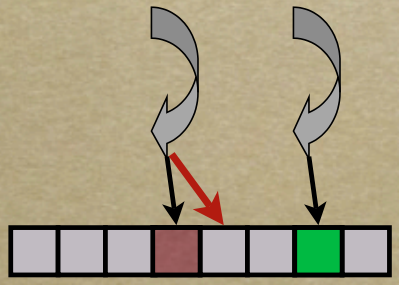
- Tasks run to completion (do not preempt)
  - while(1) {runNextTaskOrSleep();}
- Two kinds of function
  - Synchronous: can only run in a task (main)
  - Asynchronous: can run in a task or interrupt
    - Asynchronous code can preempt
    - Compile-time race condition detection
- Posting is how you go from async to sync

Concurrency Model

- T2 has the same basic concurrency model
  - Tasks, sync vs. async
- T2 changes the task semantics
  - TinyOS 1.x: post() can return FAIL, can post() multiple times (shared slots)
  - T2: post returns FAIL iff the task is already in the queue (single reserved slot per task)



TinyOS 1.x



T2

Scheduler

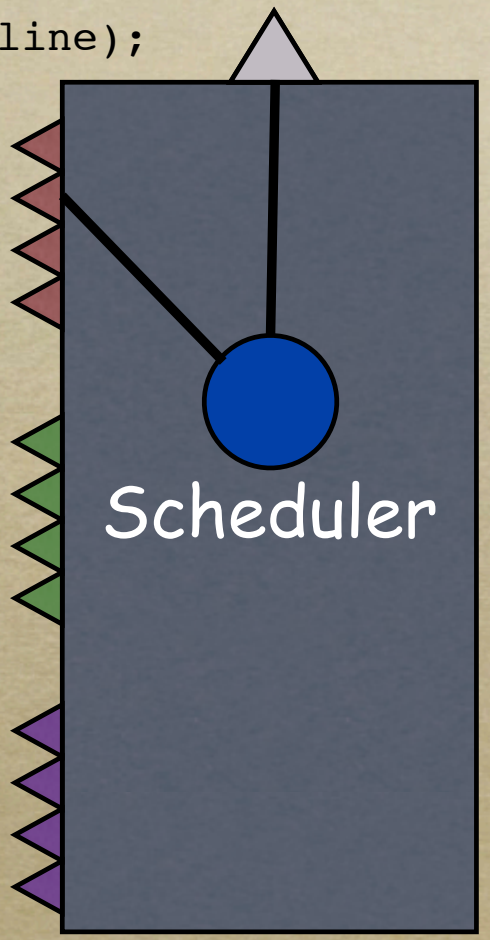
- Common (but mostly disappeared) TinyOS complaint: why no task priorities?
  - Scheduler was the one part you could not change (built into the language)
  - Some application domains may really need them
- T2 solution: scheduler is a component, tasks are just another interface
  - nesC compiler transforms task/post into used interfaces

Scheduler, Continued

```
interface TaskEDF {
  command async error_t post(uint16_t deadline);
  event void run();
}
```

```
interface TaskBasic {
  command async error_t post();
  event void run();
}
```

```
interface TaskPriority {
  command async error_t post();
  event void run();
}
```



Core Effects

- Platform/chip decomposition makes a platform diversity much easier
- Scheduler can enable a wider range of applications

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Varying Specificity

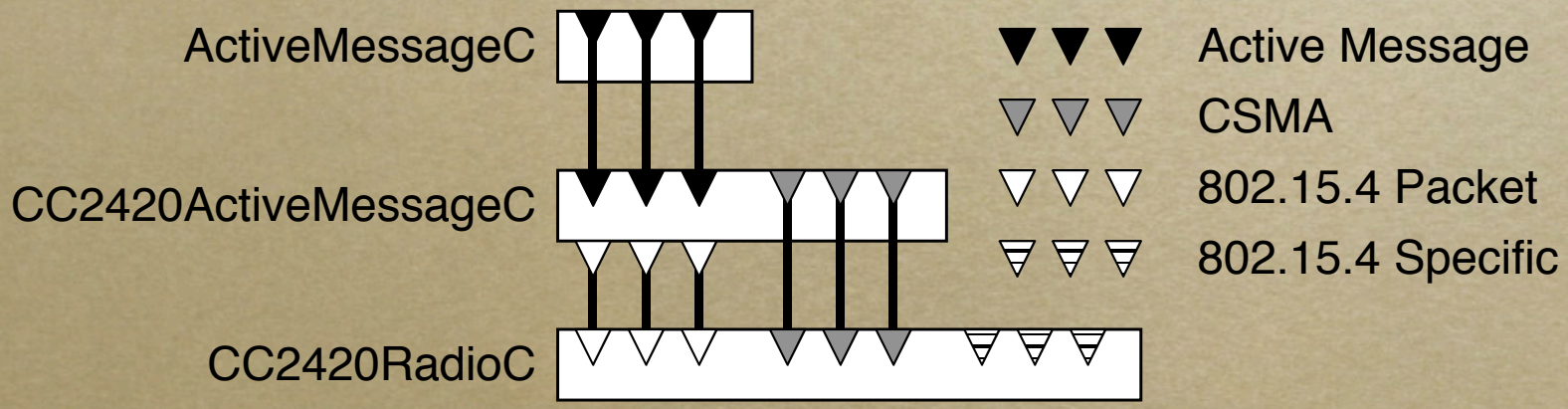
- I send packets
- I send packets and expect acks
- I sometimes turn off CSMA
- I sometimes turn off address decoding

More Varying Specificity

- I need a timer, roughly ms granularity, some jitter is OK
- I need a timer, 32kHz granularity, as low jitter as possible
- I need a timer, 32kHz granularity, that works in low power mode X

Multi-Layer Abstractions

- Many fine-grained layers of increasing power and specificity



Partial Virtualization

- Some abstractions are shared and virtual
  - Basic timers, packet transmission
- Some are dedicated and physical
  - Compare register B2 for CC2420 MAC timing
- Some are shared and physical
  - SPI bus between CC2420 and flash storage

Their Effect

- Make it clear when your code is portable vs. platform specific
  - Improve robustness by making exchanging hidden dependencies for explicit ones
- Enable a wider range of applications
  - Support full spectrum of simple and portable to high-performance subsystems

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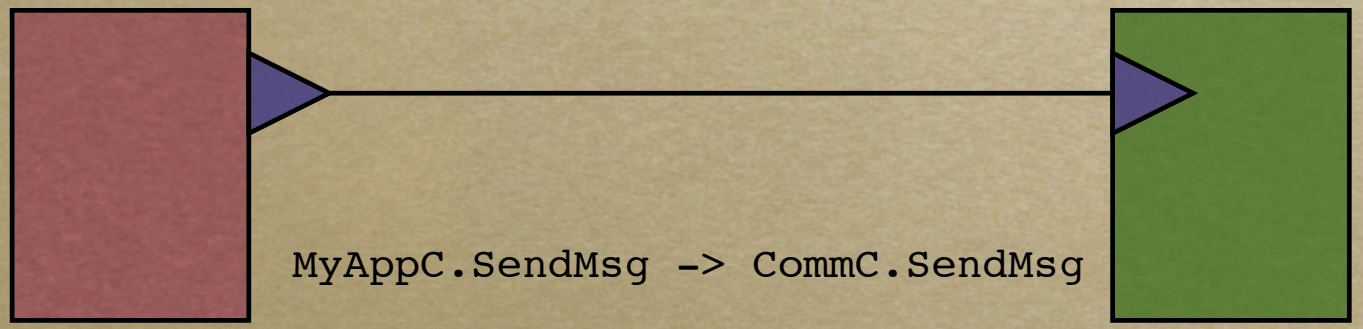
Static Binding

- nesC components can only interact through interfaces

```
interface SendMsg {...}
```

```
configuration MyAppC {
  uses interface SendMsg;
}
```

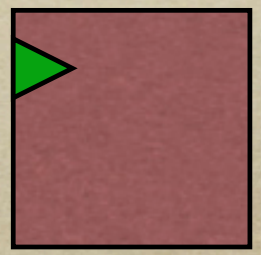
```
configuration CommC {
  provides interface SendMsg;
}
```



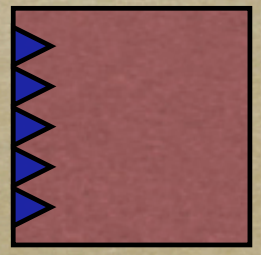
Static Binding, Continued

- Run-time vs. compile time parameters

```
interface CC2420Register {
  command uint16_t read(uint8_t reg);
  command uint8_t write(uint8_t reg, uint16_t val);
  command uint8_t strobe();
}
component CC2420C {
  provides interface CC2420Register;
}
```



```
interface CC2420StrobeReg {
  command uint8_t strobe();
}
component CC2420C {
  provides interface CC2420StrobeReg as SNOP;
  provides interface CC2420StrobeReg as STXONCCA;
   ....
}
```



Static Allocation

- You know what you'll need: allocate it at compile-time (statically)
- Depending on probabilities is a bet
  - I.e., "it's very unlikely they'll all need to post tasks at once" = "they will"
- You know what components will use a resource, can allocate accordingly
  - In some cases, static allocation can **save** memory

Saving Memory

```
module Foo {
  bool busy;

  command result_t request() {
    if (!busy() &&
        post fooTask() == SUCCESS) {
      busy = TRUE;
      return SUCCESS;
    }
    else {
      return FAIL;
    }
  }
```

TinyOS 1.x

```
module Foo {
  bool busy;

  command result_t request() {
    return post fooTask();
  }
```

T2

Effects

- Static binding improves robustness
  - Push as many checks to compile-time as possible
  - Bad parameters become impossible compositions
- Static allocation improves robustness
  - You can make safe assumptions in code
  - Code is shorter, simpler, and more deterministic

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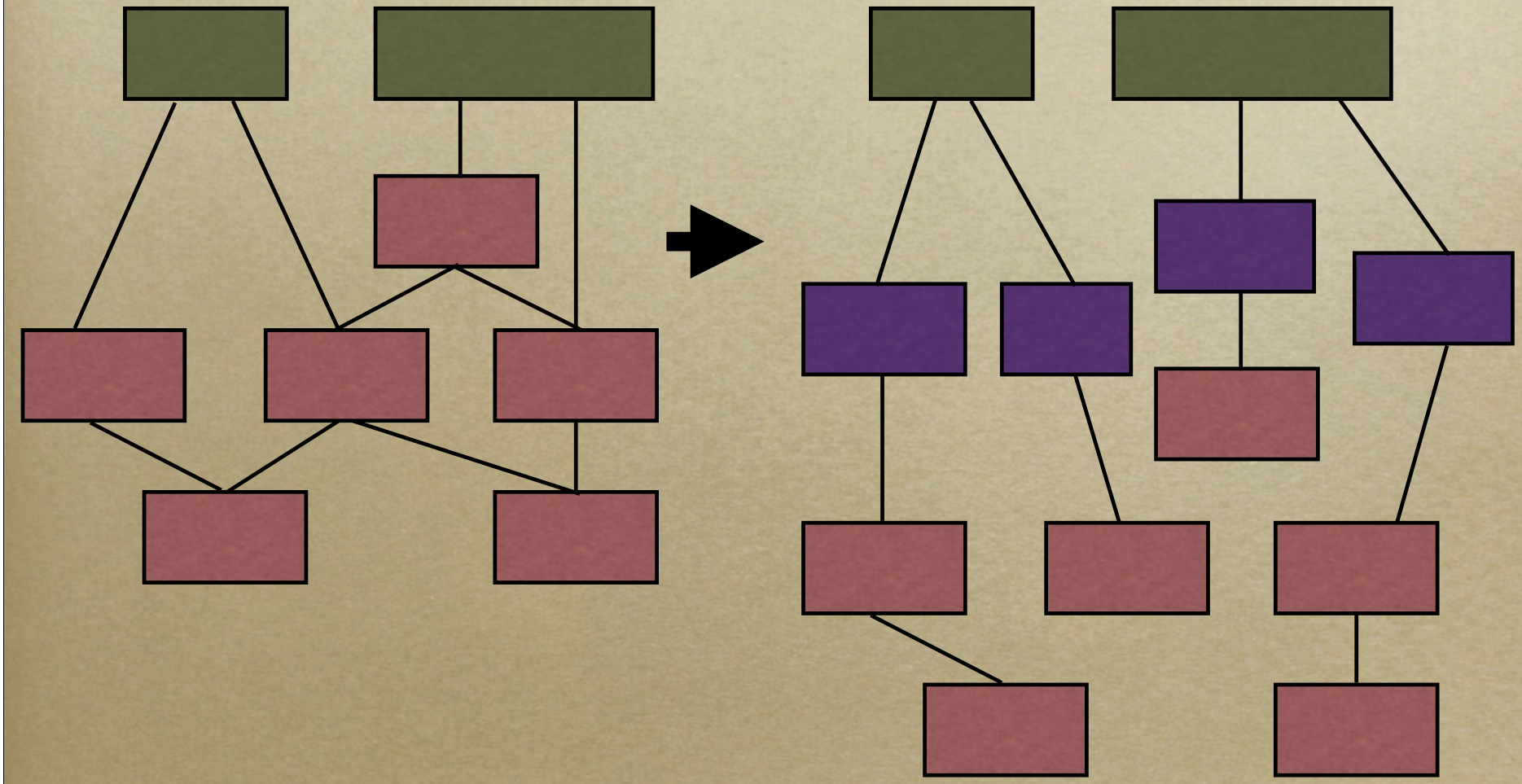
Service Distributions

- Applications that push the envelope need arbitrary component composition
- Most don't push the envelope, though
- A service distribution is a set of services with compatible implementations and policies, presented as a unified API
  - An abstraction boundary

More Service Distributions



Example Distribution: OSKI

- A range of communication services
  - Broadcasting
  - Collection routing
  - Serial port
  - Addressed single-hop
- A power management policy
  - Turn service instances on and off
  - A service turns off iff all its instances are off

Effects

- Service distributions improve robustness
  - Preclude many unforeseen compositions
  - Can test services as a whole
- Service distributions make building applications easier
  - A real API, rather than a collection of independent components

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The State of the Art Today

- Sensor networks are different
- Revisiting old problems and assumptions
  - Different resource constraints
  - Different design tradeoffs
  - Sometimes new problems, sometimes not
- Opening the doors to innovation
- Systems to support a huge range of requirements, applications, and abstractions

Components

- Innovation and exploration require flexible systems
  - Arbitrary boundaries
  - Arbitrary composition
- Current systems maximize flexibility
  - TinyOS: collections of components
- This flexibility sacrifices reliability
  - E.g, TinyOS -> SOS
  - Inherent tension between flexibility/reliability

The Hidden Cost

- Arbitrary flexibility prevents you from promising anything
  - Robustness, performance, etc.
- You can still build applications, but it's hard and time consuming
- T2: leverage five years of experience
  - Not all flexibility is needed
  - Can we trade off some for improved usability and performance?

The Research Questions

- Questions of grammar
  - How do we write a component?
  - How do we connect components?
  - How do we specify concurrency?
- Questions of style
  - How do we decompose a system into components (granularity, state sharing)?
  - How do we compose those components?
  - How do those components interact?

TinyOS 1.x
nesC

T2

Questions