Knit: Component Composition for Systems Software

Alastair Reid, Matthew Flatt, Leigh Stoller, Jay Lepreau, Eric Eide

University of Utah
Why Components?

- Everyone is writing too much code
  - Not enough code reuse
  - Hard to reconfigure
  - Hard to understand
  - Hard to test/verify

- Exceptions: Click, Scout, Ensemble, Fox, MMLite, OSKit, …
Why Not Components?

- **Overhead**
  - Runtime
  - Programmer time

- **Advanced systems don’t work with C**

- **Complex component interdependencies**
  - Locking restrictions
  - Top/bottom-half
  - Bootstrap sequence
Goal of Knit Project

To make components practical for systems programming
Key to Achieving Goal

Static configuration language

- Enables error detection
- Enables optimization
Target#1: The Utah OSKit [SOSP’97]

- Approximately 500 components:
  Device drivers, bootstrap code, TCP/IP stacks, filesystems, SNMP, etc.
- Doesn’t impose architecture
- $10^6$ lines of code from Linux, FreeBSD, NetBSD, Mach, Fluke, etc.
Outline

- Introduction
- The Knit component model
  - Atomic units
  - Compound units
  - Automatic Initialization
  - Detecting Configuration Errors
- Implementation and Performance
- Open issues
### Atomic Units [PLDI’98]

#### serve_web

```c
int serve_web(...) {
    if (...) {
        serve_cgi(...);
    } else {
        serve_file(...);
    }
}
```

#### Required Packages

- `-loskit`
- `-DKERNEL`
- `-DHAVE_CONFIG`
Compound Units [PLDI’98]

files

serve_file

serve_cgi

select_server

serve_web
Initialization

init_x86();
init_IDE();
init_VM();
init_threads();
init_filesys();
init_main();
Initialization

```
init_x86();
init_IDE();
init_threads();
init_filesys();
init_main();
```
When Can We Break Cycles?

1. Component ‘contains’ subcomponents

2. No dependency between initializers
Automatic Initialization

- Knit generates initialization sequence
- Cycles are resolved by refining initialization dependencies in units

Experience
- 5% of units need dependencies refined
- Programmers find initialization a big win
Detecting Composition Errors

threads

filesys

console

panic

ethernet
Detecting Composition Errors

- threads
- filesys
- console
- panic
- ethernet

locks  interrupts
Detecting Composition Errors

threads
  ↓
filesys
  ↓
console
  ↓
panic
  ↓
ethernet

locks

interrupts
Detecting Composition Errors

- threads
- filesystem
- console
- panic
- ethernet

locks

interrupts
Detecting Composition Errors

- threads
- filesys
- console
- panic
- ethernet

- locks
- interrupts
Detecting Composition Errors

threads \rightarrow \text{filesys} \rightarrow \text{console} \rightarrow \text{panic} \rightarrow \text{ethernet} \leftarrow \text{locks} \leftarrow \text{interrupts}
Detecting Composition Errors

- threads
- filesystem
- console
- panic
- ethernet
- locks
- interrupts
Detecting Composition Errors

- context(threads) <= ProcessContext
- context(filesys) <= context(threads)
- context(console) <= context(filesys)
- context(panic) <= context(console)
- NoContext <= context(ethernet)
- ProcessContext < NoContext
Extensible Constraint System

- Constraint system propagates properties through component interconnections
  - Knit can detect global errors
- Constraint system is extensible
  - In context X, don’t do Y
  - Type system for Modular IP Routers (e.g., Click)
  - …
Knit

- Supports C, assembly and object files
- Separates interconnections from code
- Automatic initialization
- Extensible constraint system
- Allows cyclic component dependencies
- Allows multiple instances of components
- Text based
Outline

- Introduction
- The Knit component model
- Implementation and Performance
- Open issues
Implementation (Unoptimized)
Performance

- Component cost should not distort system structure
- Reduce overhead by eliminating function calls
Click and Clack

- Click modular network router from MIT [SOSP’99]

- Clack
  - Re-implementation of Click using Knit
  - Similar performance to Click

- Many small components
Performance of Clack

<table>
<thead>
<tr>
<th>Time per Packet</th>
<th>Unoptimized</th>
<th>Monolithic</th>
<th>Optimized</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>100%</td>
<td>79%</td>
<td>65%</td>
</tr>
</tbody>
</table>
Open Issues

- Is Knit general purpose?
  - Need more users
  - Need more applications
- Is the constraint system extensible enough?
- Implicit linking vs. explicit linking?
Conclusions

- State of the art component system for C
- Targeted at systems code
  - Automatic initialization
  - Detects local and global errors
  - Low performance overhead

- Available ASAP: http://www.cs.utah.edu/flux/