Dynamic Probes - Debugging by Stealth

Update and Work-in-Progress

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Australia

Suparna Bhattacharya

suparna@in.ibm.com

IBM Linux Technology Centre

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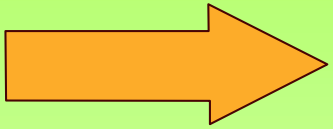
What & Why?

- Low-level system debugging facility
  - Operates in extreme conditions
  - Live Systems vs. Development
  - Automated Kernel Debugger (SMP capable)
  - Dynamically Customisable Trace/Logger
  - Universal (User/Kernel/Interrupt mode code)
  - Fine grained Storage Profiling
  - Low System Overhead
- Proven technology from OS/2
- Enabler for other RAS offerings
  - Dynamic Complex Assertion Checking
    - Trigger analysis from first-point-of-failure
  - Ad-hoc Tracing

What is a Probepoint?

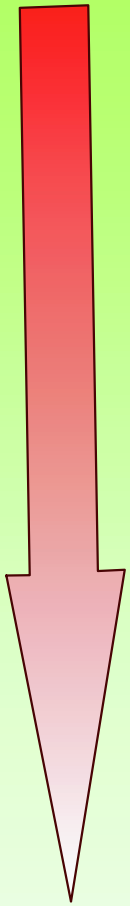


Automated Breakpoint

- Trapping Breakpoint (INT3, SVC 255):
  - ➡ Unlimited number in general
  - ➡ Usually generalises across platforms
  - ➡ Module-level Specification
  - ➡ Can miss events under MP
- Hardware Watchpoint (DRegs):
  - ➡ No missed events under MP
  - ➡ Limited number in general
  - ➡ Doesn't generalise across platforms
  - ➡ Virtual/Physical Storage Specification

Probepoint Specification

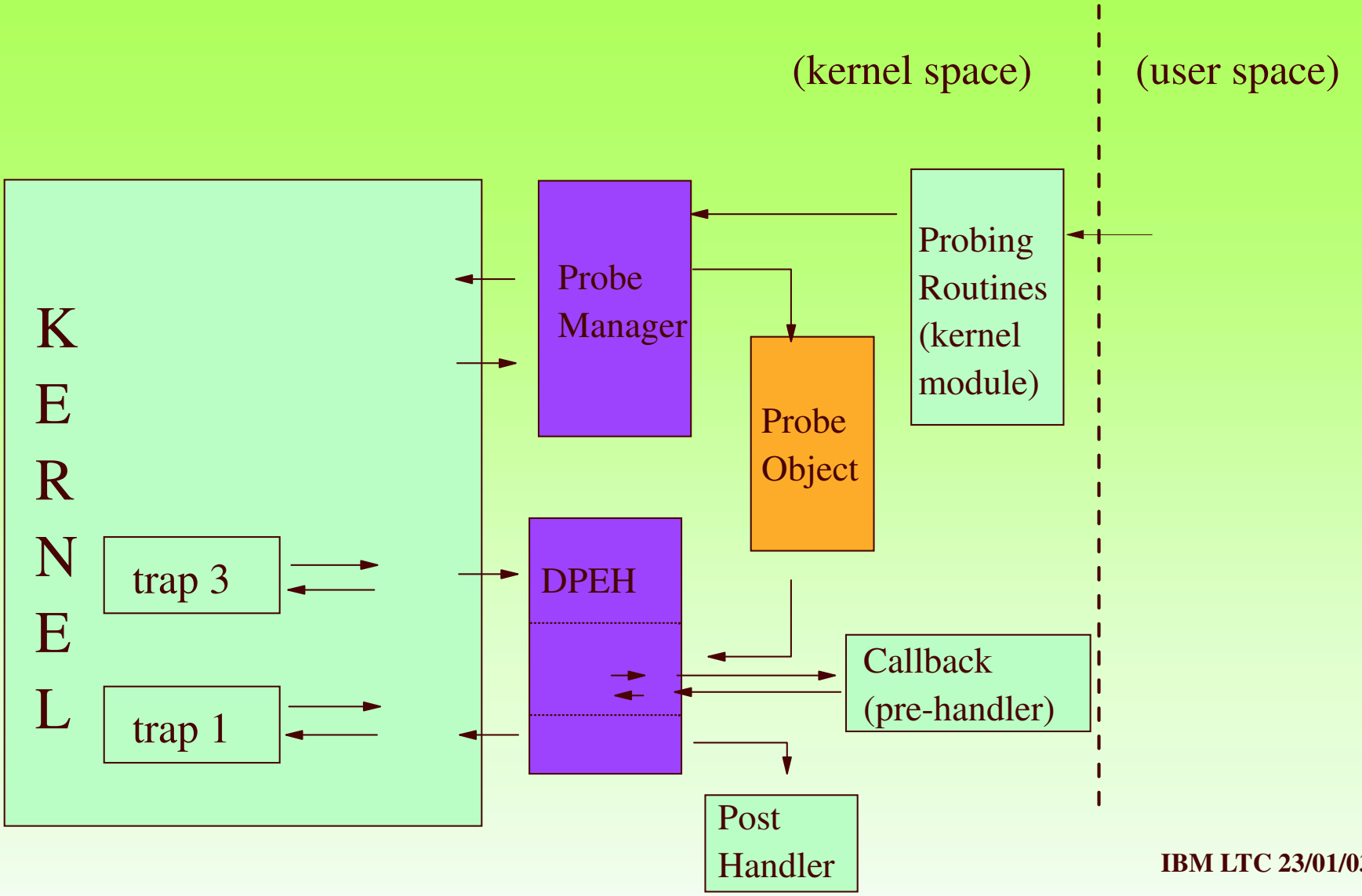
Local



Global

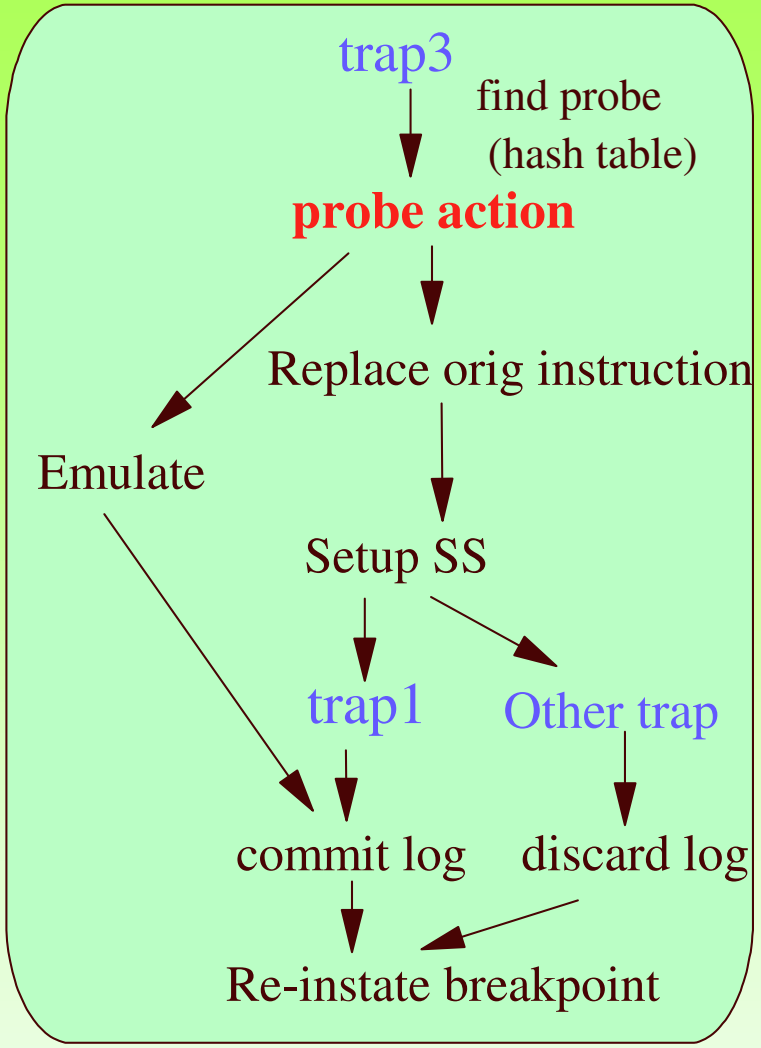
Locality	User Specification	Characteristics	Internal Specification	Typical Usage
Per-process	virtual address/ module-offset	Privatises shared pages via COW		GDB, ptrace
Per-module	module-offset	Global, inserted using aliased virtual address.	inode-offset for non-resident and user modules. Virtual address for resident kernel modules.	DProbes (User probes)
Virtual Storage	virtual address	Limited to Kernel space or one process		Debug H/W kernel debuggers watchpoints (Kprobes)
Physical Storage	physical address	Limited to resident modules		Debug H/W kernel debuggers watchpoints

Basic Probe Components



Probe Mechanism

- Breakpoint
  - Instruction Replacement (INT3)
- Single-stepping or Emulation
- Interrupts disabled
- Per-CPU probe context
- Log Buffer Commital
- Recursion
- SMP Serialization & Locking
- SMP probe misses window*
- Zombie breakpoints



Patch Organization

- 2.5
  - Kernel Probes (kprobes) (< 400 LOC)
  - Debug Register Management (dr_alloc)
  - Watchpoint Probes (kwatchpoints)
  - User Space Probes (uprobes)
  - Dprobes driver (rest of dprobes function)
- 2.4
  - Full Dprobes kernel patch using Kernel Hooks
- User Space
  - Dprobes command (RPN based probe language input)
  - Dprobes C Compiler (dpcc) (C-like interface to RPN)

Kernel Probes

```
struct kprobe {
        struct list_head list;

    /* location of the probepoint */
     kprobe_opcode_t *          addr;
      /* Called before addr is executed. */
     kprobe_pre_handler_t       pre_handler;
     /* Called after addr is executed, unless... */
     kprobe_post_handler_t      post_handler;
      /* ... called if executing addr causes a fault (eg. page fault) */
      kprobe_fault_handler_t    fault_handler;

    /* Saved opcode (which has been replaced with breakpoint) */
     kprobe_opcode_t opcode;
};
```

Kprobes Interfaces

```
static void test_probe_handler(struct kprobe *p, struct pt_regs *regs)
{
        printk("p1 hit\n");
        count++;
        return;
}

struct kprobe p1 = {
        .addr           = (u8 *)0xc0116120, /* do_fork */
        .pre_handler    = test_probe_handler,
};
```

.

-> int register_kprobe(struct kprobe *);

-> int unregister_kprobe(struct kprobe *);

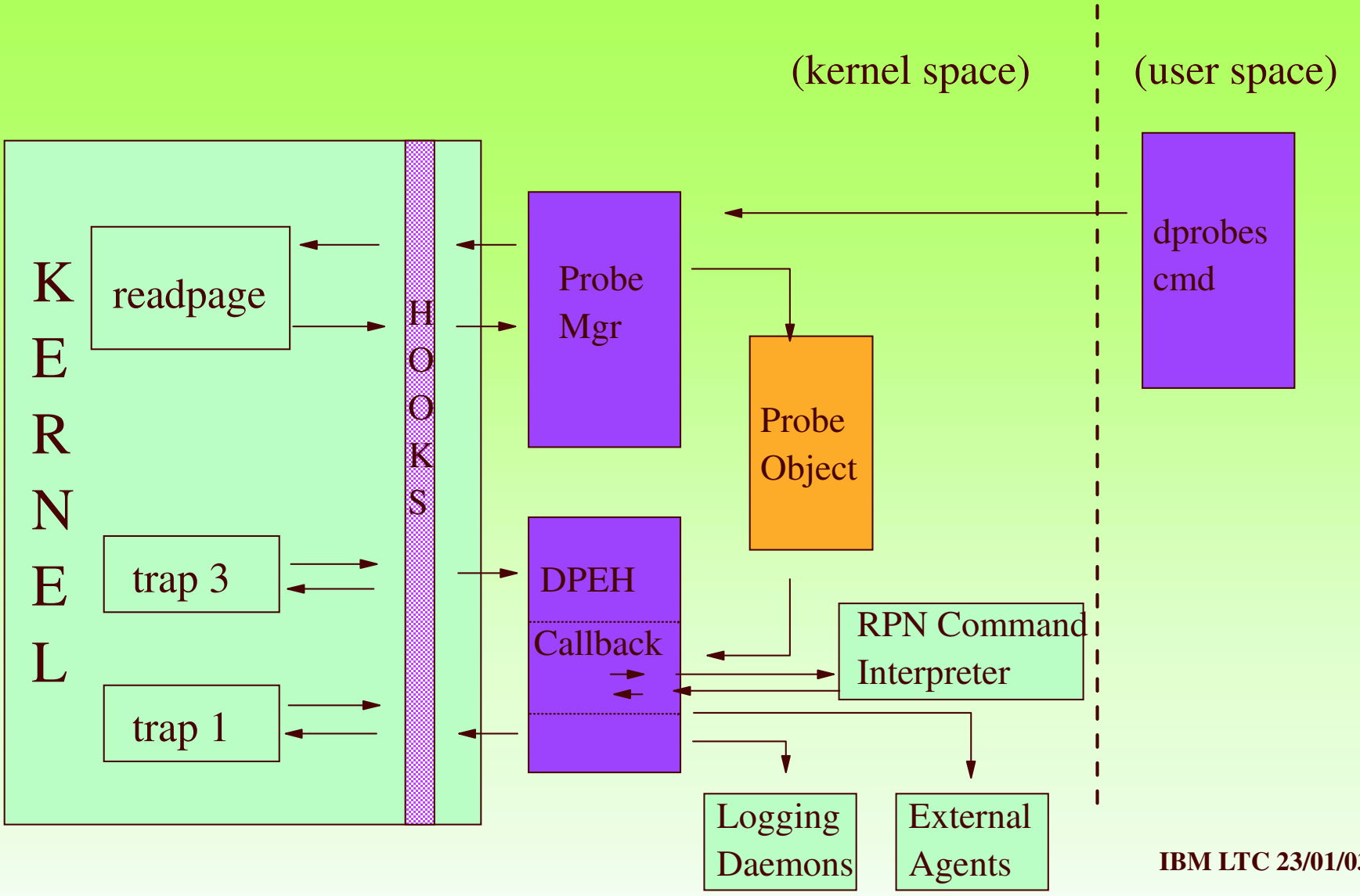
Watchpoint Probes

- Fired on specific types of memory accesses
  - Execute, Write, Read or Write, IO
  - Specified by virtual address, range (non-context specific)
- Exploits H/W debug registers
  - 4 on Intel x86, 1-4 byte range
  - Debug Reg. Alloc patch - co-ordinate w/ other Debug Facilities
- Enables fine-grained storage profiling with LTT
  - e.g. Monitoring specific kernel data structures
- Kwatchpoints patch
- Pagepoints extension

User Probes

- System wide global
  - Common to all Instances of an object module
  - No Copy-On-Write !
  - Shared Library, Executable program
- Identified by <inode, offset> rather than addr
- On-demand insertion (no forced loading/pinning of pages)
  - low memory overhead (can have large no. of probes)
  - e.g. by intercepting readpage aops for the inode
- Uprobes patch
  - minimal support (physical placement; search on probe hit)
  - extends kprobes struct with <inode, offset>

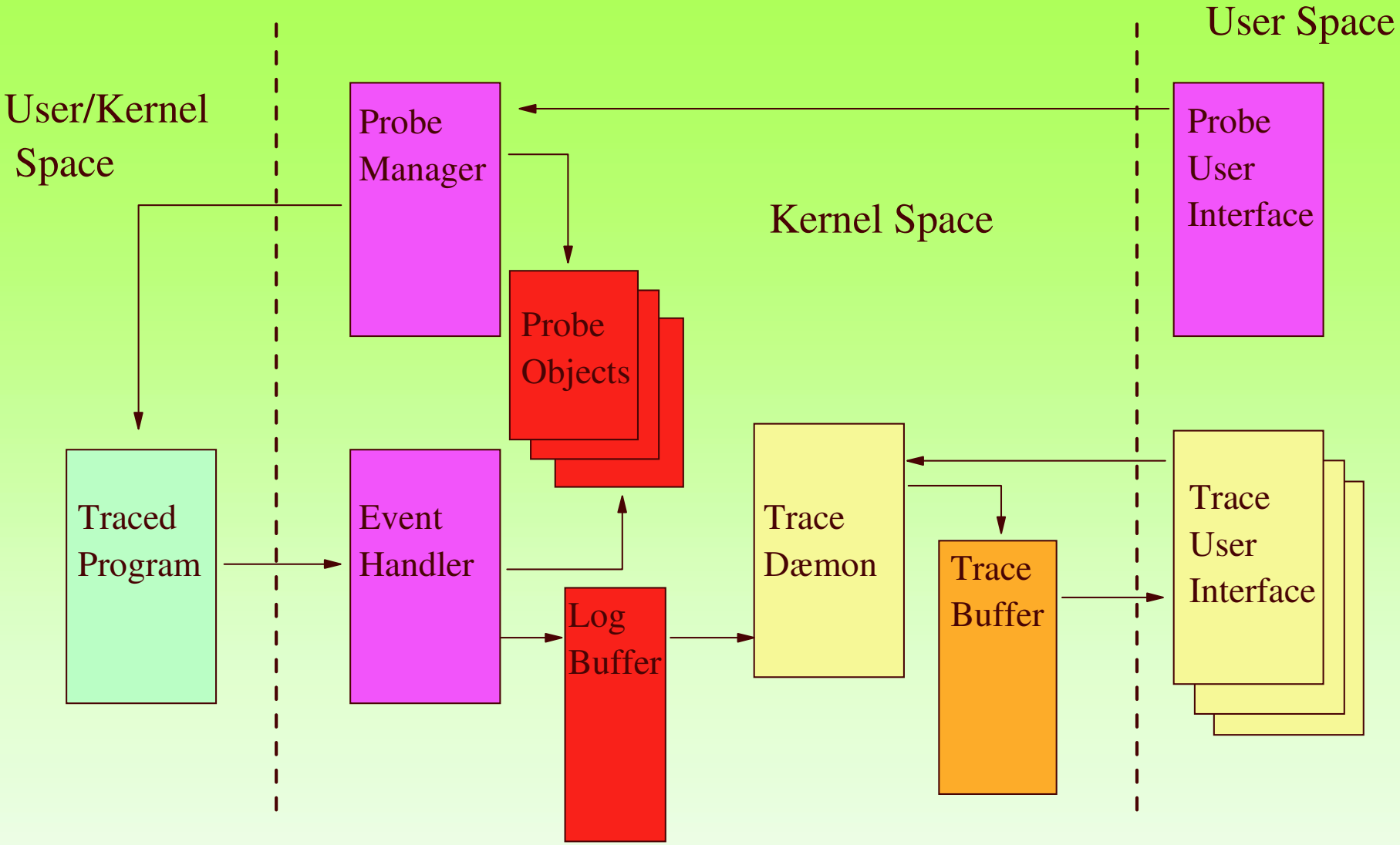
Full DProbes Components



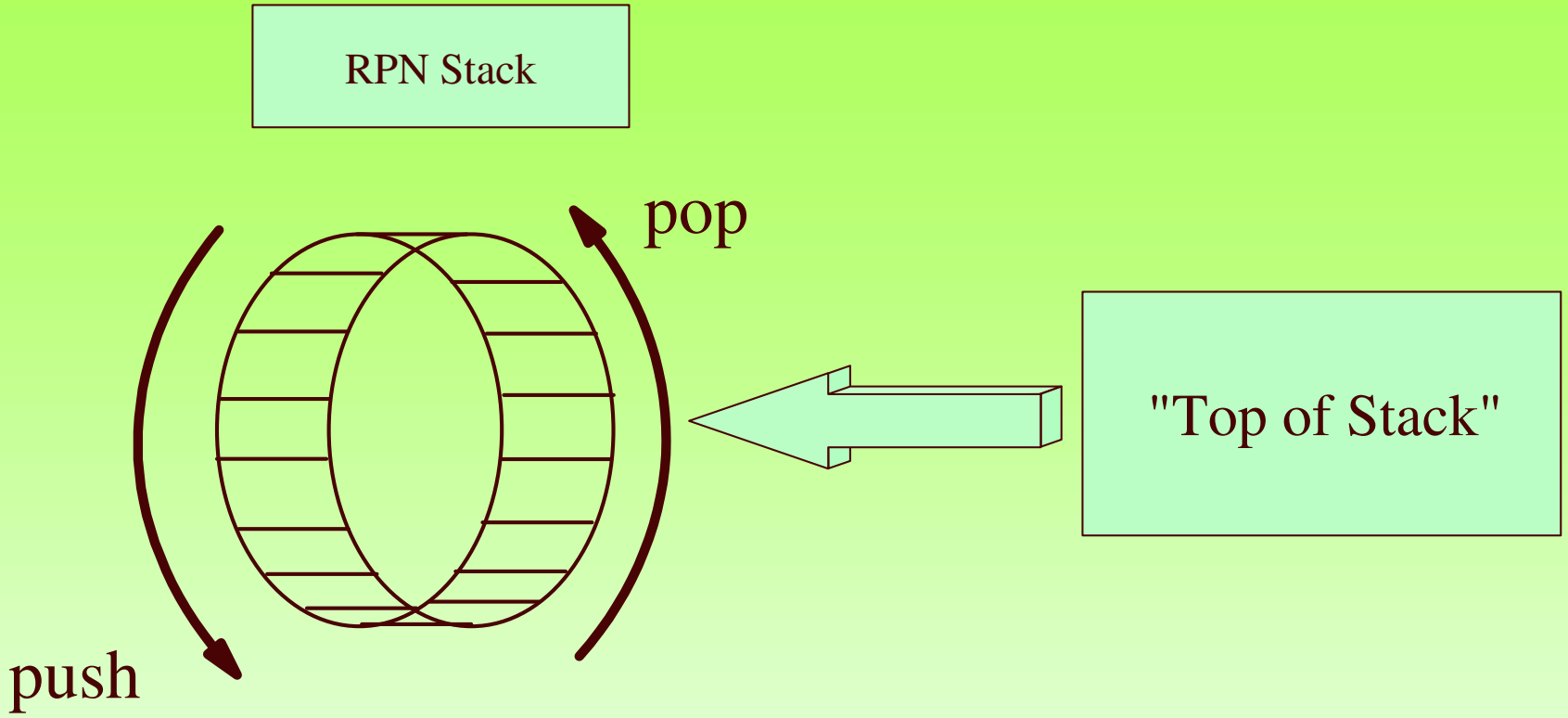
External Facilities

- Logging Daemons
  - Syslog (klogd) - default
  - COM1 and COM2
  - Universal Dynamic Trace - LTT (Opersys)
  - POSIX Event Logging
- External Agents
  - KDB
  - SGI Kernel Crash Dump
  - Core Dump

Trace Daemon Interface



RPN Interpreter



- Access to CPU (low-level) resources
- "Easy" to generate from a HLL (dpcc) - compare with Java

RPN Command Categories

- Arithmetical/Logical
- Program Flow
  - ➡ Conditional
  - ➡ Subroutine calls
- External Triggers
- Local (i.e. per-probe) and Global Variables
- Log Buffer (per-processor)
- Exception Handling
- System Resources:
  - ➡ Registers, Memory, IO

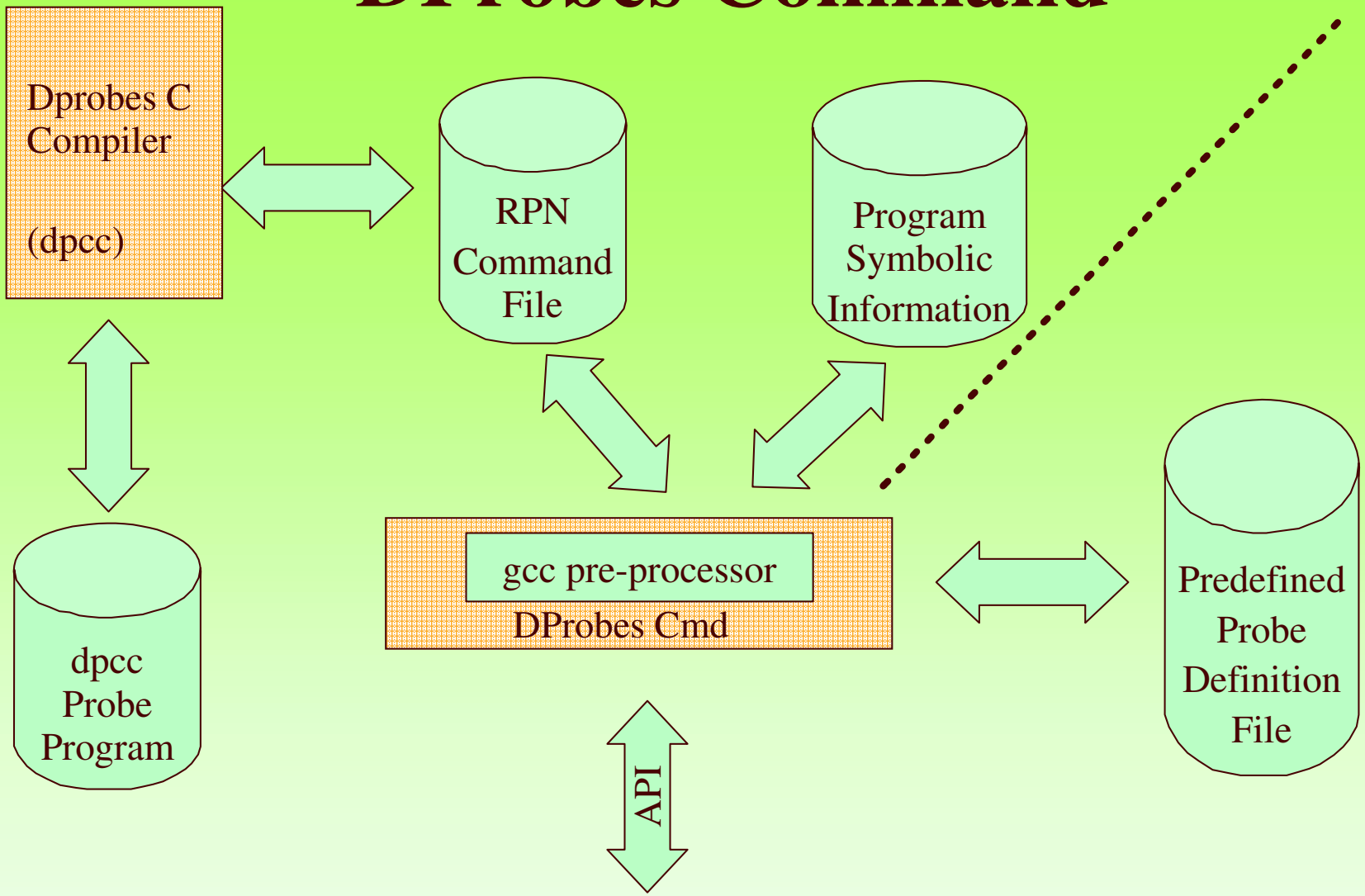
The DProbe High-Level Language Compiler

- Allows a C-like language to be used for probe definitions.
- Compiler (dpcc) generates RPN code.
- Allow variables from probed program to be referenced.
- Supports a set of simulated c-RTL routines.
- Needs original program to be compiled with debug opts.
- Language is fully described in dpcc.groff man pages.
- See numerous examples packaged with dpcc.

Example dpcc Probe Program

```
#pragma MODNAME("/usr/src/linux/vmlinux")
#pragma PROBEPOINT_LOCATION("fork.c:589")
#pragma MODTYPE(kernel)#pragma
PROBEPOINT_HANDLER("test")
/* Demonstrates logging local variable (2.4.18 kernel)
   do_fork:589 => blank line after *p = *current;
   Logs the task_struct pointed to by p.
   View output in system log e.g. /var/log/messages.
*/
void test()
{
   log_probe_expr("*p");
}
```

DProbes Command



Employment of DProbes

- Sysfs based driver using kprobes - dynamic printk insertion (Rusty Lynch)
  $ echo "add <address> <message>" > /sys/noisy/ctl
- Field problems (OS/2 dtrace):
  - Obscure cause-symptom relation & live system:
  - ➡ Page Manager Bugs, Probes in Context Switch !
  - ➡ Parcel Bomb Problems (async msg induced, OS/2 PM)
  - ➡ Device Driver/Device Interface Bugs (interrupt handler probes)
- During development
  - ➡ Large-scale (internal) instrumentation
  - ➡ Fault Injection
  - ➡ Ad-hoc Profiling
  - ➡ Debugging races, timing sensitive problems

Work-In-Progress/Future Work

- Dprobes driver for 2.5 using kprobes
- IA-64 port
- More instruction emulation ?
- Single-step out-of-place
- Pagepoints
- Sampler probes ?
- Init-time probes ?

Architectures currently supported: ia32, s390, s390x, ppc, ppc64

16. Questions?

Mailing List: dprobes@oss.software.ibm.com
Web Page:
http://oss.software.ibm.com/developerworks/opensource/linux/projects/dprobes
System RAS Projects page: http://systemras.sourceforge.net

Core Team:

Richard Moore (RAS Architect)
S. Vamsikrishna (Project Maintainer)
Bharata B. Rao
Gary Hade (ia64)
Michael Grundy (s390 & ppc)
Subodh Soni
Suparna Bhattacharya
Thomas Zanussi (dpcc)

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Andrea Arcangeli (SuSE)
Karim Yaghmour (OperSys)
Maneesh Soni (IBM)

BACKUP SLIDES

9. Performance

Quantitative measurements

- Pentium 90Mhz (11ns cycle time)
- order of 8-16µs

Qualitative results

- Tracepoints on entry to pagefault routines - negligible
- Tracepoints on kernel heap routines - negligible
- Tracepoints on all kernel APIs - negligible
- Tracepoints on all kernel routines (4000) - somewhat noticeable!

10. Porting Considerations

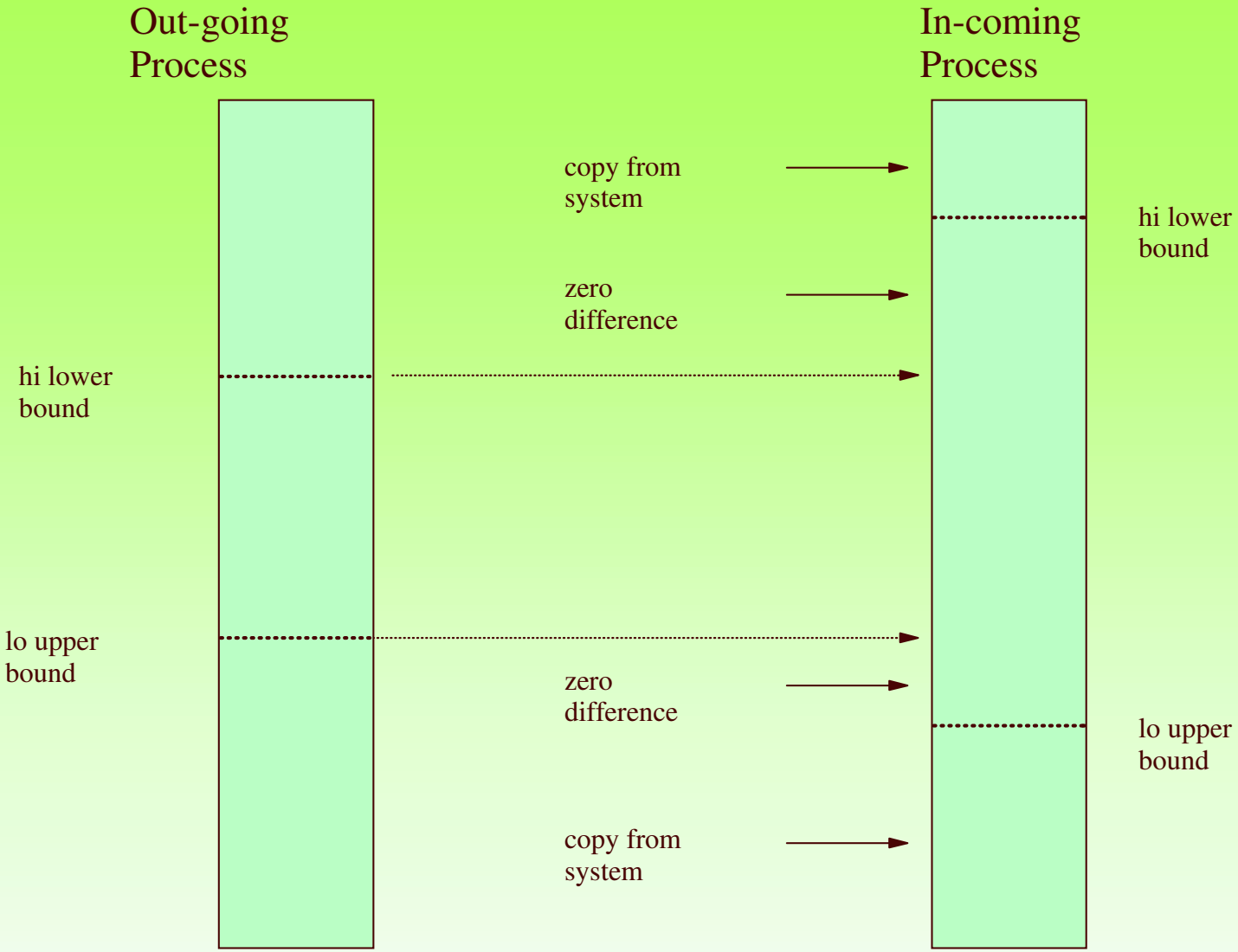
Linux on other H/W:

- Integer size
- RPN Instruction set - register set - endian issues
- Probepoint implementation - INT3 equivalent
- Single-step mechanism - atomicity with breakpoint
- Serialisation - Cache & MP
- Watchpoint implementation

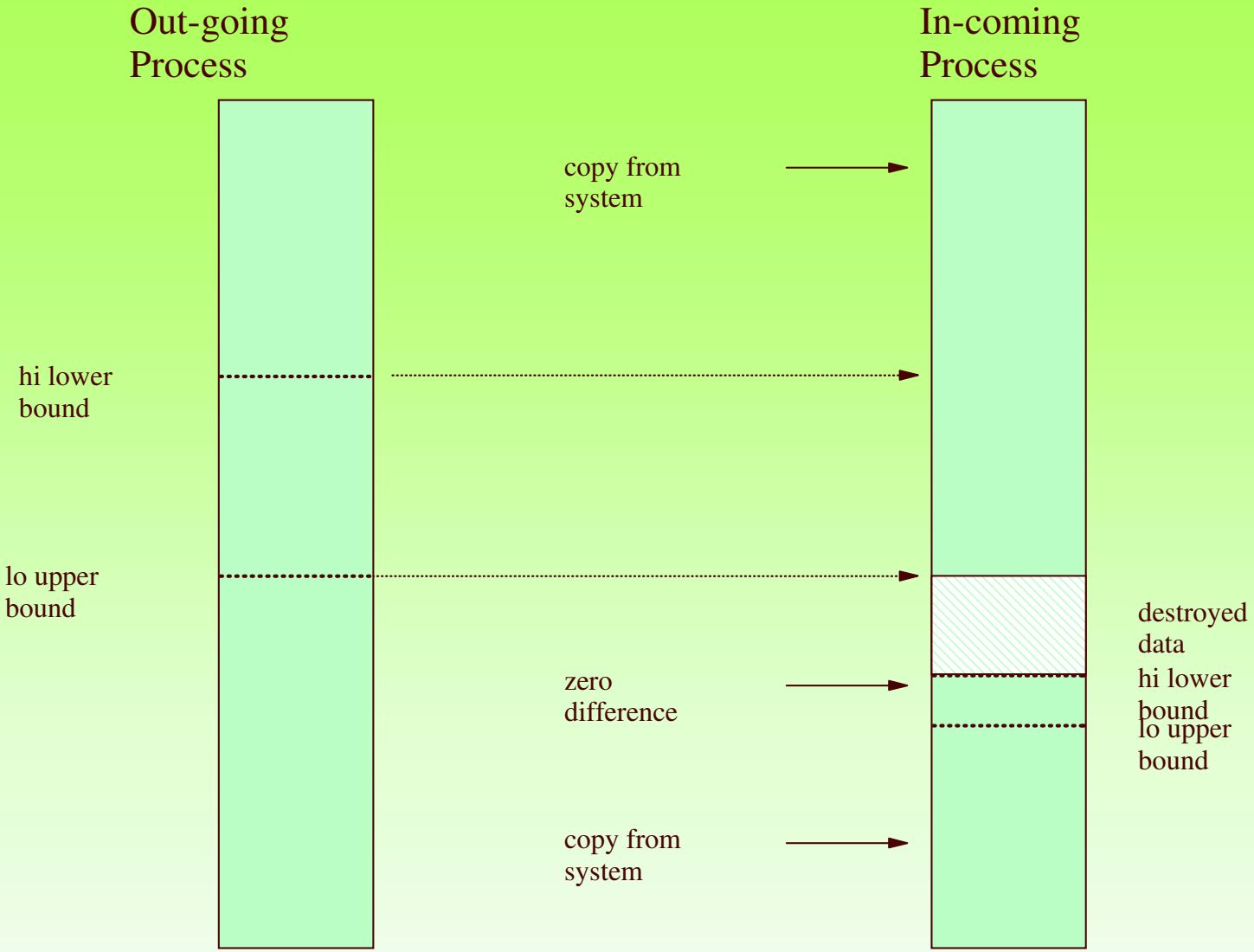
To Other OS's:

- Module management
- Page management
- Symbolic support - ELF
- Memory aliasing
- Fault interception

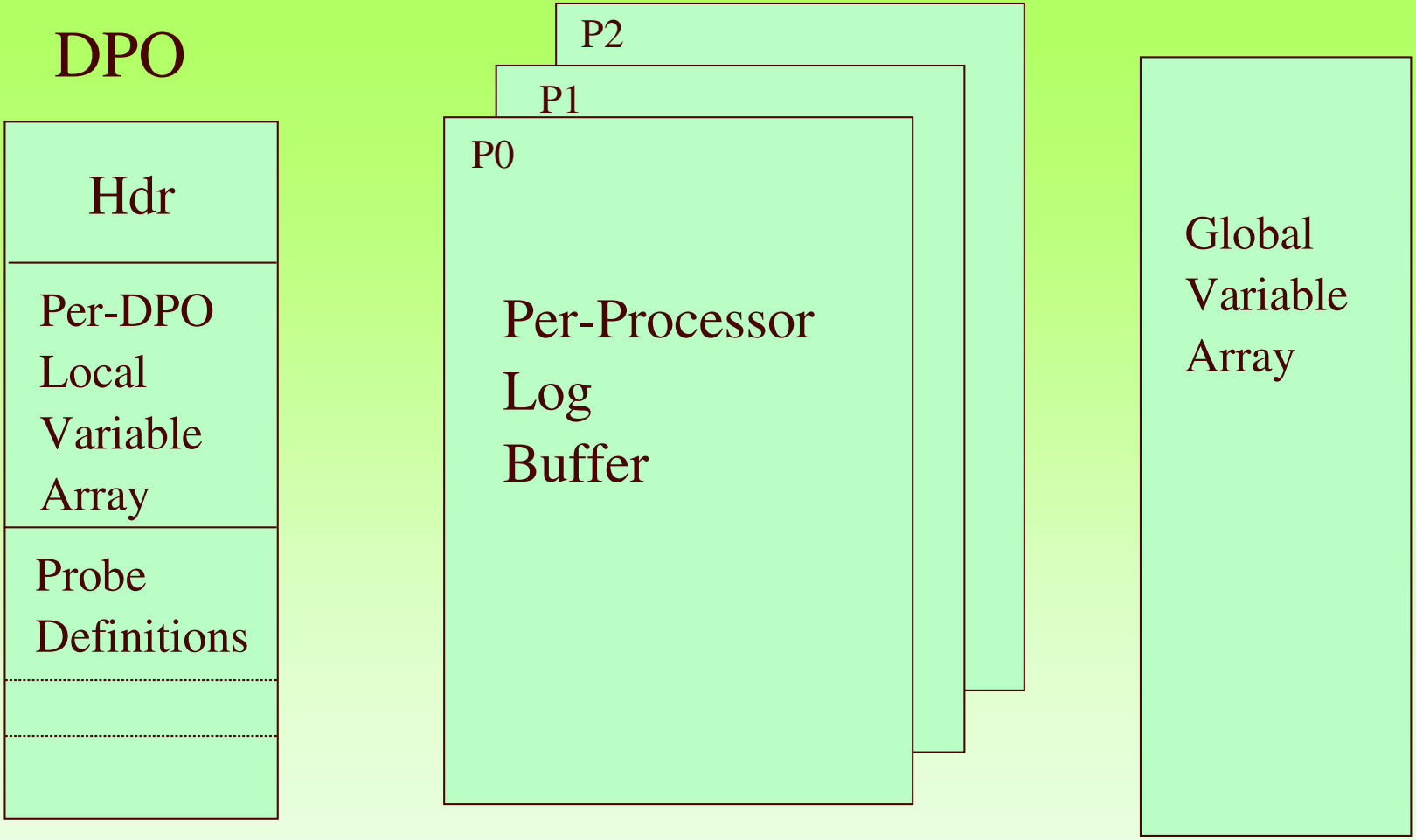
11. Process Switching Example (1)



12. Process Switching Example (2)



RPN Program Storage



Example RPN Probe Program

```
name = bzImage
modtype = kernel
major = 1
jmpmax = 32
logmax = 100
vars = 1

offset = kill_proc
opcode = 0x55
minor = 1
ignore = 0
maxhits = 1000
inc lv,0
push d,16
push r, esp
log mrf
exit
```

Further info => man ./dprobes.lang.groff

13. Command Invocations

```
INSERT:
dprobes -i <rpn_file_name>
dprobes -i <rpn_file_name> -s <symbol_file_name>

QUERY:
dprobes -q [-x] [-a]

REMOVE:
dprobes -r <rpn_file_name>
dprobes -r -a

GET LOCAL/GLOBAL VARS:
dprobes -g -a
```

Further info => man ./dprobes.groff