TECHNISCHE UNIVERSITÄT DRESDEN

Department of Computer Science Institute for System Architecture, Operating Systems Group

LEGACY REUSE

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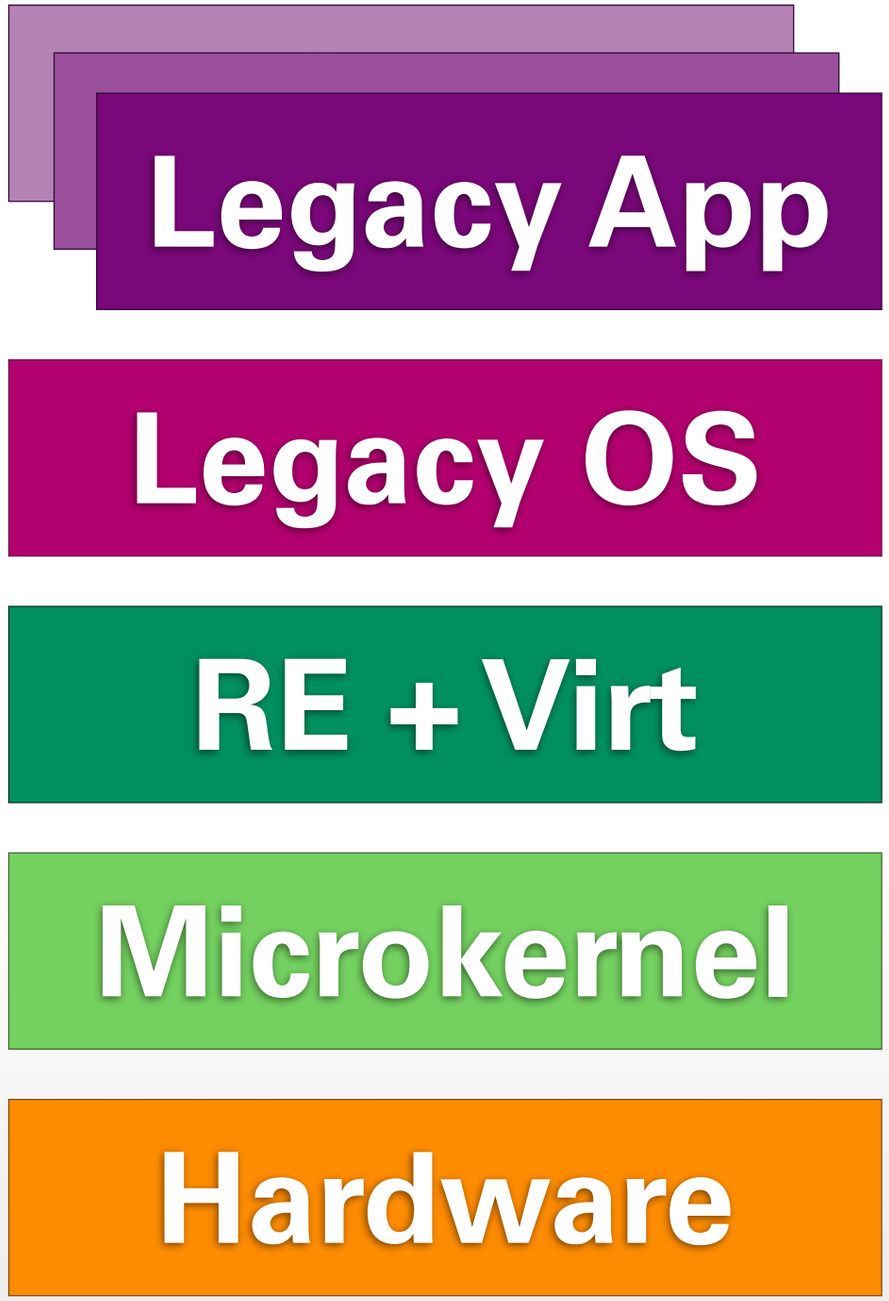
THIS LECTURE ...

- **So far ...**
  - Basic concepts, resources, ...
  - Virtualization
- **Today:**
  - Operating System Personalities
  - How to reuse existing infrastructure
  - How to make applications happy

SINGLE SERVER

Getting applications the easy way:

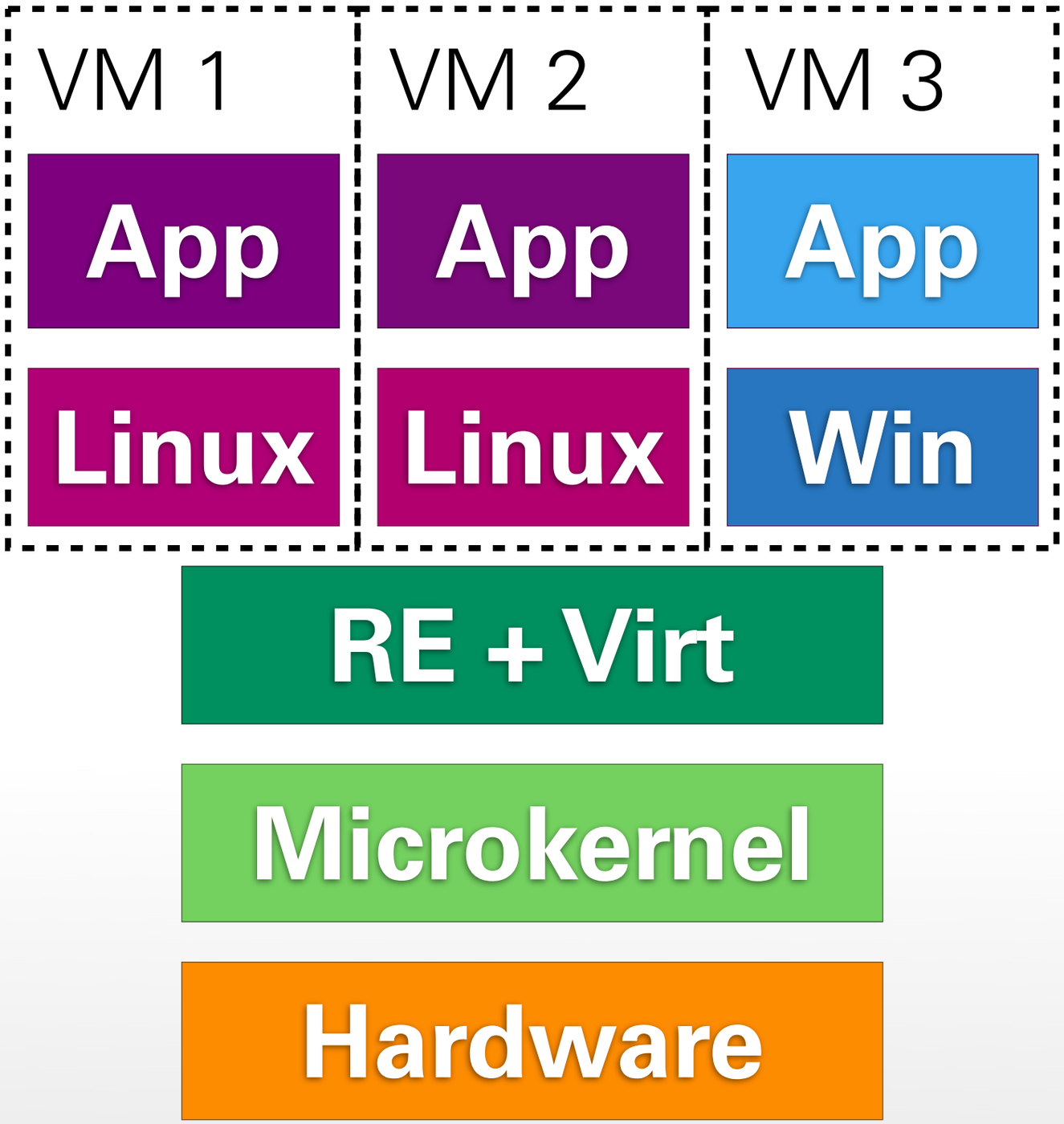
- Virtualize OS + app
- All services provided legacy OS (e.g., Linux)
- Original implementation, good app compatibility
- Limited isolation



MULTI-VM SETUP

Multiple VMs:

- Improved isolation
- Communication via virtual network
- Run same OS multiple times
- Run different OSes concurrently



VIRTUALIZATION

- **Virtualization:**
  - Reuses legacy OS + applications
  - Applications run in their natural environment
- **Problem:** Applications trapped in VMs
  - Different resource pools, namespaces
  - Cooperation is cumbersome (network, ...)
  - Full legacy OS in VM adds overhead
  - Management overhead, multiple desktops?

MAKING THE CUT

- **Hardware level** (virtualization)
  - Legacy OS + applications on top of new OS
- **Operating system level** (e.g., Wine)
  - Legacy OS‘s interfaces reimplemented on top of new OS
- **Application level**
  - Applications, Toolkits, frameworks, libraries ported to new OS

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OPERATING SYSTEM PERSONALITIES

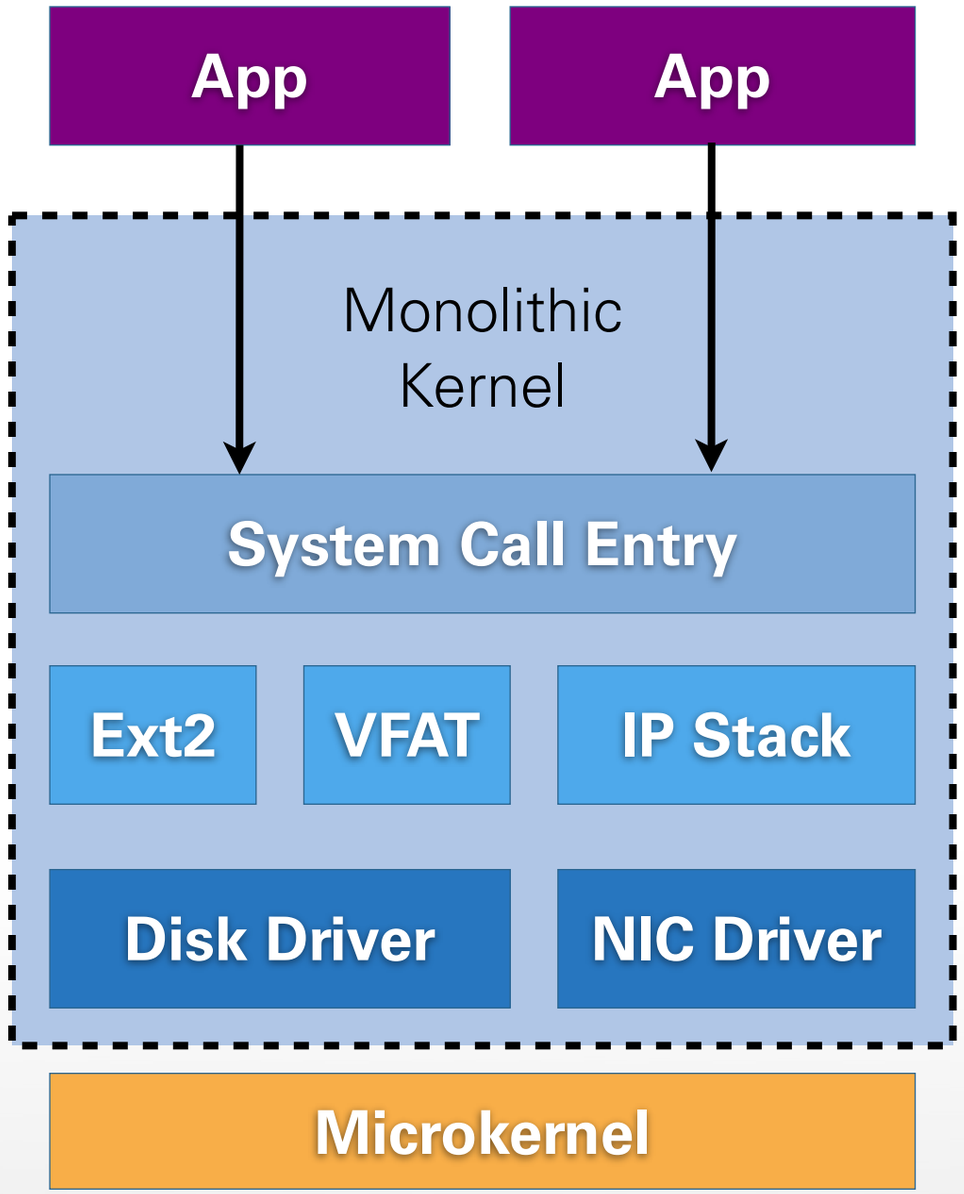
WHAT WE WANT ...

- **Goal**: get application running
- **How?**
  - Determine what application needs
  - Provide the needed APIs on our new OS
- **Secondary goal**: reuse established APIs
  - Makes porting of more applications easy
  - Benefit from previous work, concepts

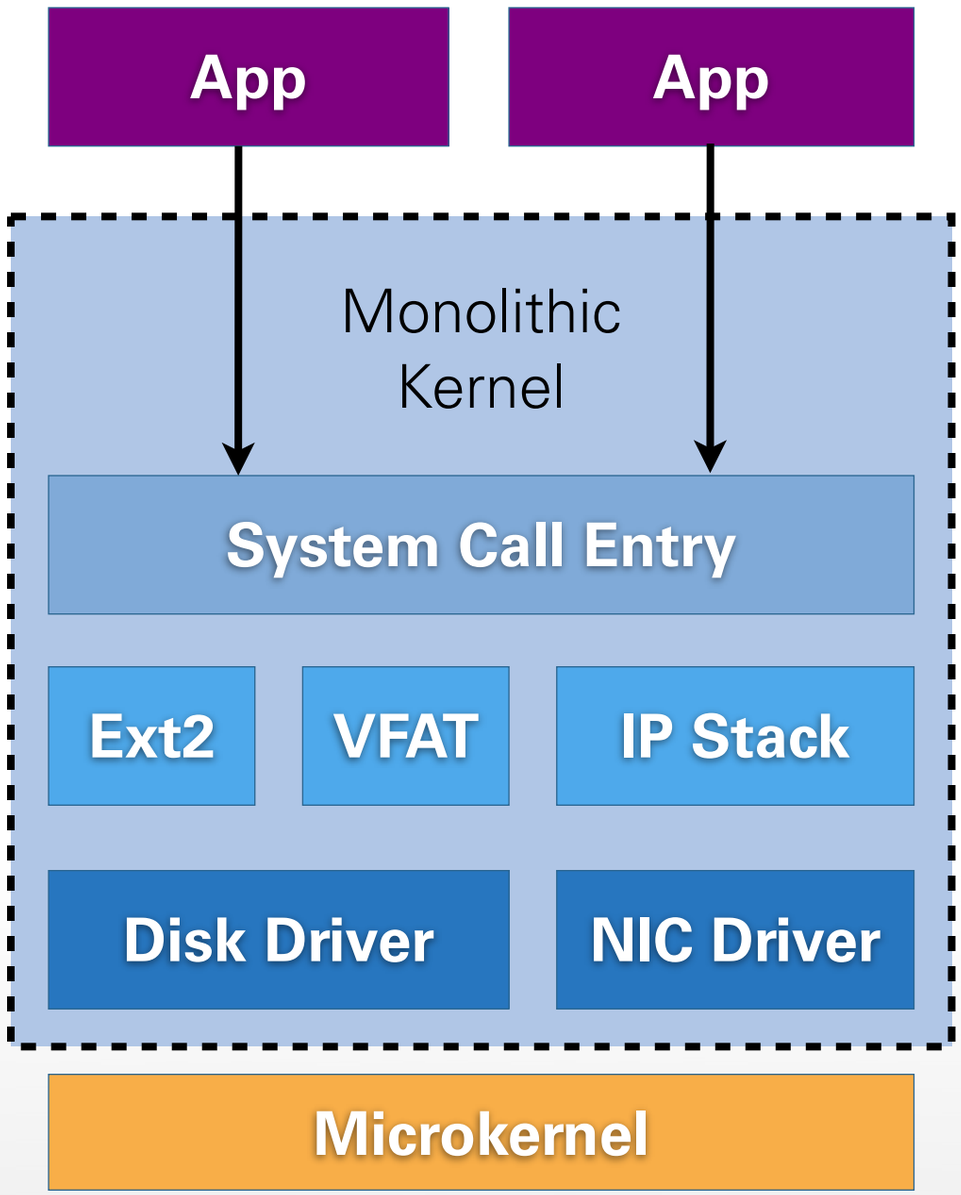
OS PERSONALITY

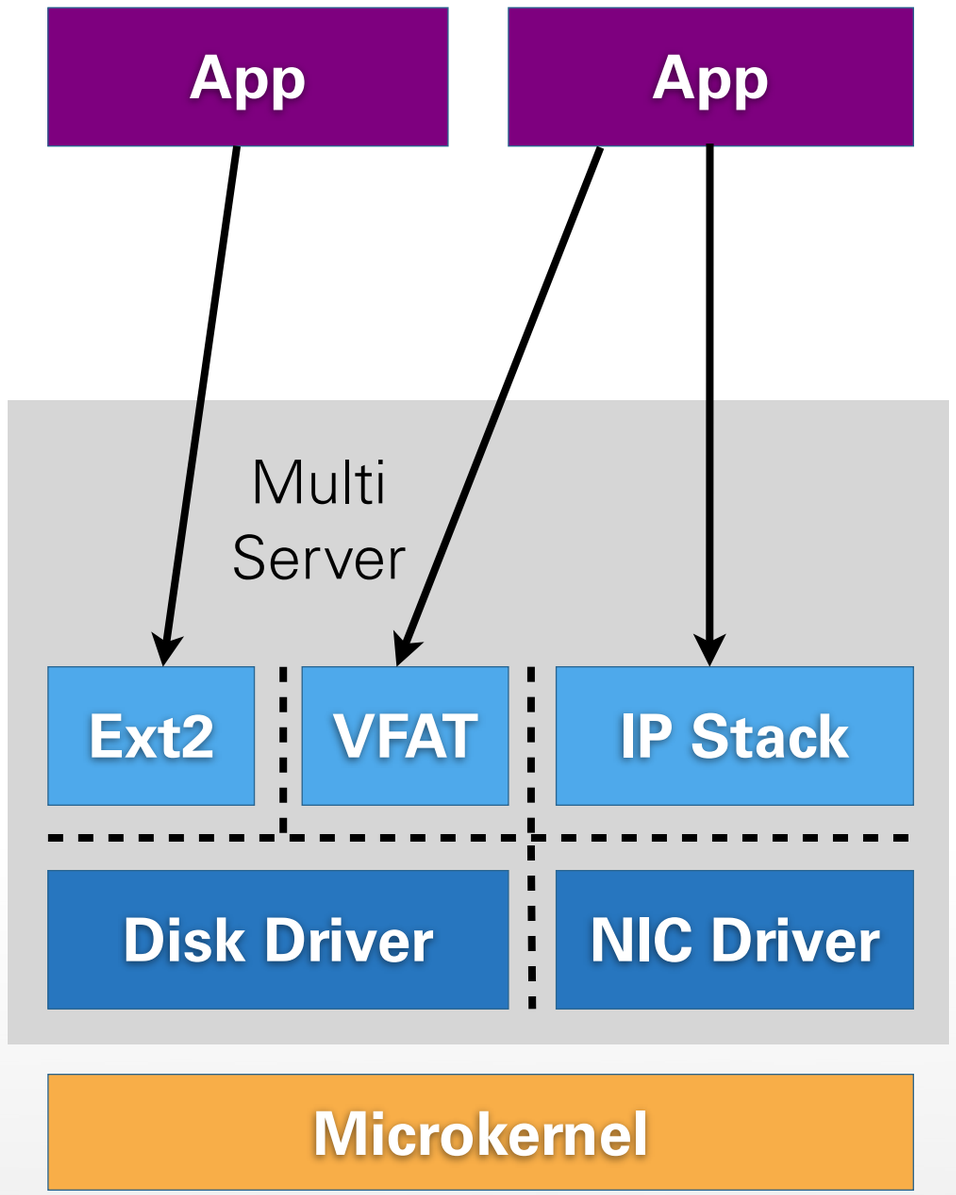
- **Idea:** Adapt at OS / application boundary
  - (Re-)Implement legacy APIs, not whole OS
  - May need to recompile applications
- **Benefits:**
  - Get desired applications, established APIs
  - More flexible, configurable, easier to achieve
  - Better integration (namespaces, files, ...)
  - Improved reliability, less overhead

SINGLE SERVER



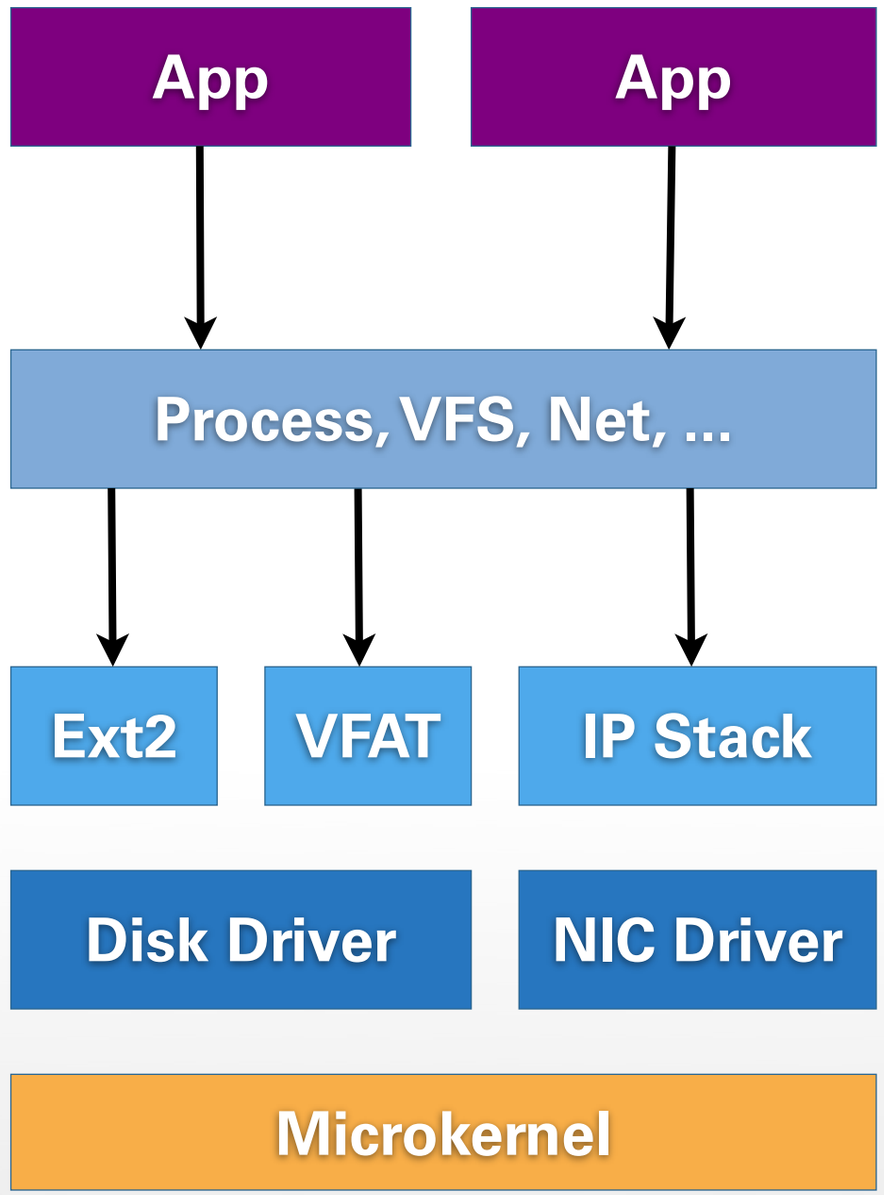
DECOMPOSITION





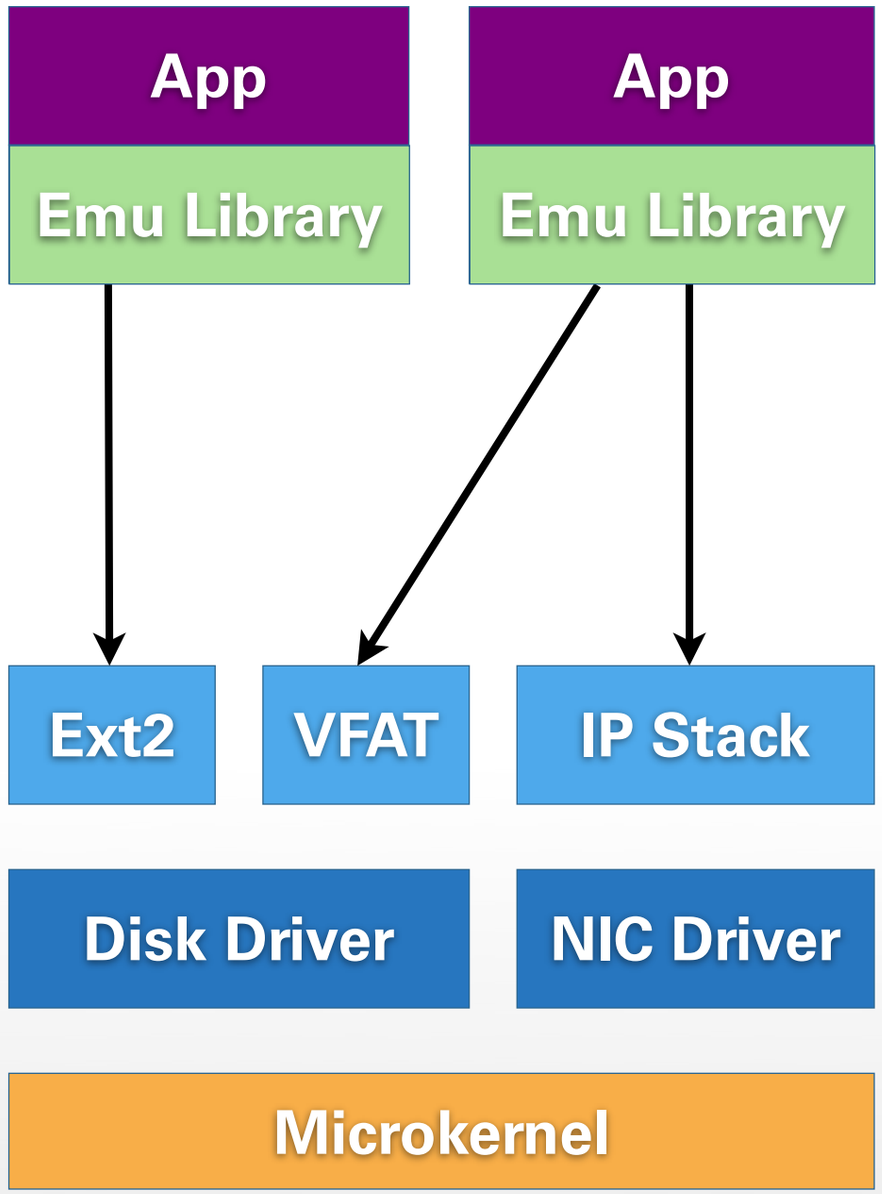
CENTRAL SERVER

- Central server provides consistent view for both:
  - **Servers:** client state (e.g., file tables)
  - **Applications:** system resources (e.g., files)
- Potential issues:
  - Scalability
  - High complexity
  - Single point of failure



EMULATION LIB

- Emulation library:
  - Linked into applications
  - Interacts with servers
  - Provides consistent view
- Each server keeps its own client state
- **In real world:** emulation library hidden below libc



POSIX STANDARD

- „Portable Operating System Interface“ is a family of standards (POSIX 1003.*)
- POSIX makes UNIX variants source-code compatible (also introduced in Windows NT)
- Defines interfaces and properties:
  - I/O: files, sockets, terminal, ...
  - Threads, synchronization: Pthread
  - System tools
- Accessible through C library

LIBC ON L4RE

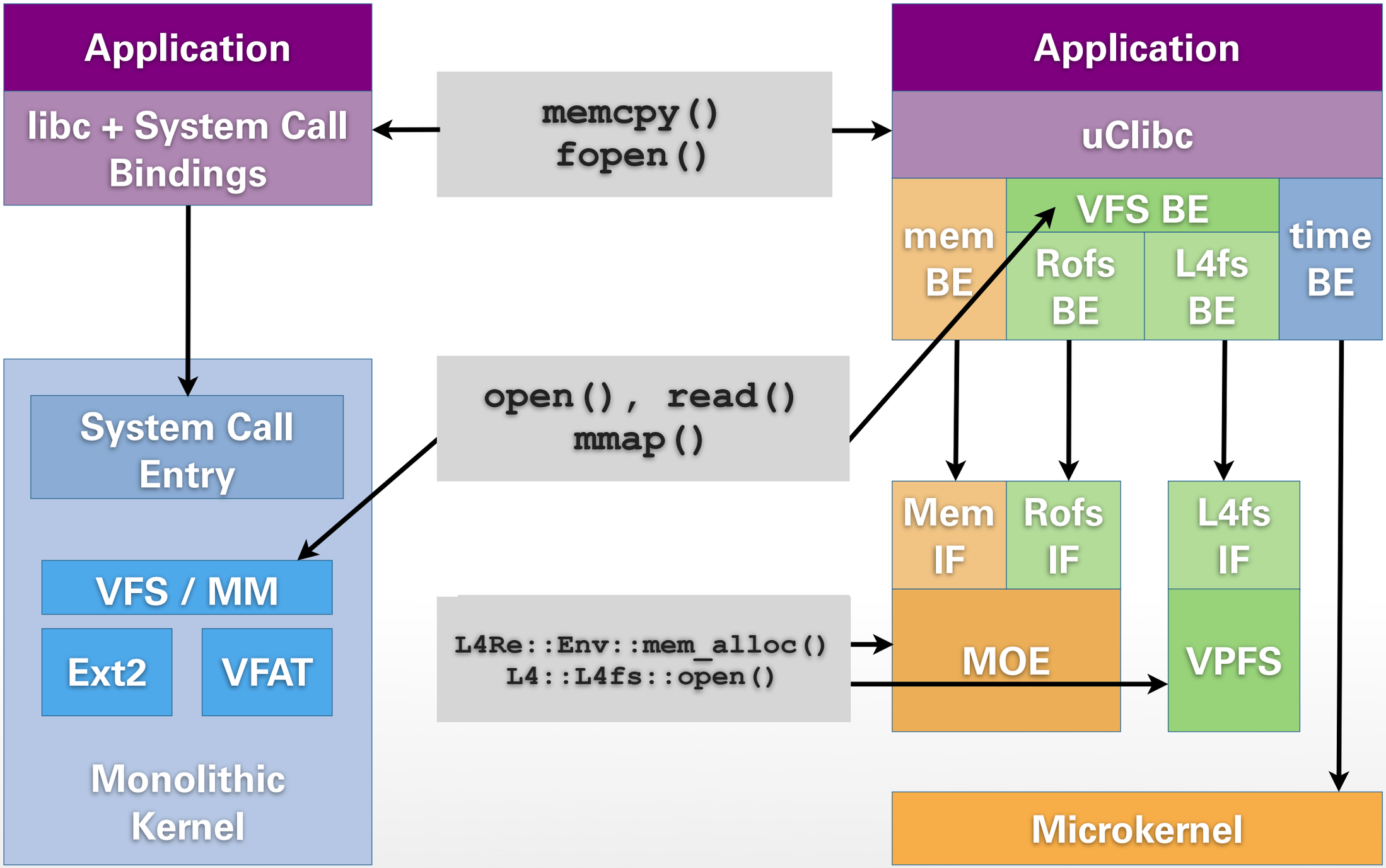
- libc support on L4Re: uClibc
  - Compatible to GNU C library „glibc“
  - Works well with libstdc++
  - Small and portable
  - Designed for embedded Linux

- Fiasco.OC + L4Re != Linux
- How to port a low-level library?

WHAT IS LIBC?

- C library abstracts underlying OS
- Collection of common functionality
- Abstraction level varies:
  - low level: **`memcpy()`**, **`strlen()`**
  - medium level: **`fopen()`**, **`fread()`**
  - high level: **`getpwent()`**
- ... and so do dependencies:
  - none (freestanding): **`memcpy()`**, **`strlen()`**
  - small: **`malloc()`** depends on **`mmap()`**
  - strong: **`getpwent()`** needs file access, name service, ...

MULTI-SERVER LIBC



LIBC BE: TIME

Example 1: POSIX time API

```
uint64_t __libc_l4_rt_clock_offset;

int libc_be_rt_clock_gettime(struct timespec *tp)
{
  uint64_t clock;

  clock = l4re_kip()->clock;
  clock += __libc_l4_rt_clock_offset;

  tp->tv_sec  = clock / 1000000;
  tp->tv_nsec = (clock % 1000000) * 1000;

  return 0;
}
```

L4Re-specific backend function (called by **`time()`** and other POSIX functions)

Replacment of POSIX function **`time()`**

```
time_t time(time_t *t)
{
  struct timespec a;

  libc_be_rt_clock_gettime(&a);

  if (t)
    *t = a.tv_sec;
  return a.tv_sec;
}
```

LIBC BE: MEMORY

Example 2: memory management

- uClibc implements heap allocator
- Requests memory pages via mmap()
- Can be reused, if we provide **`mmap()`**

- self_mem:
  - Minimalist, uses static pages from BSS
- l4re_mem:
  - Full **`mmap()`**, **`munmap()`** support
  - Requests memory as dataspaces

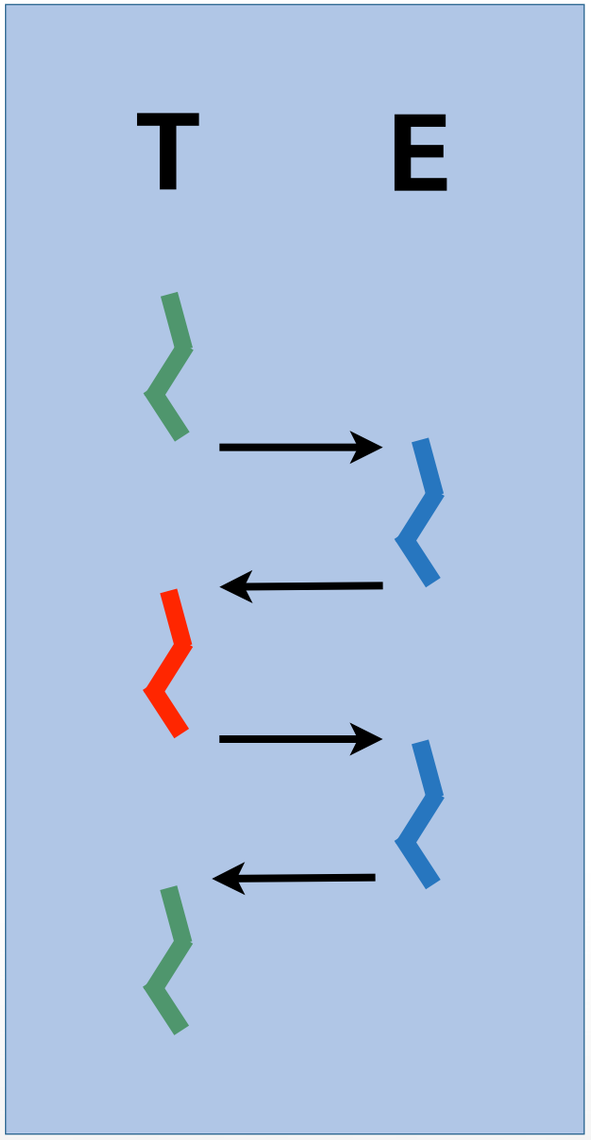
LIBC BE: SIGNALS

Example 3: POSIX signals

- Used for asynchronous event notification:
  - Timers: **`setitimer()`**
  - Exceptions: **`SIGFPE`**, **`SIGSEGV`**, **`SIGCHLD`**, ...
  - Issued by applications: **`SIGUSR1`**, **`SIGUSR2`**
- Signals on Linux:
  - Built-in kernel mechanism
  - Delivered upon return from kernel
- **How to implement signals in L4Re?**

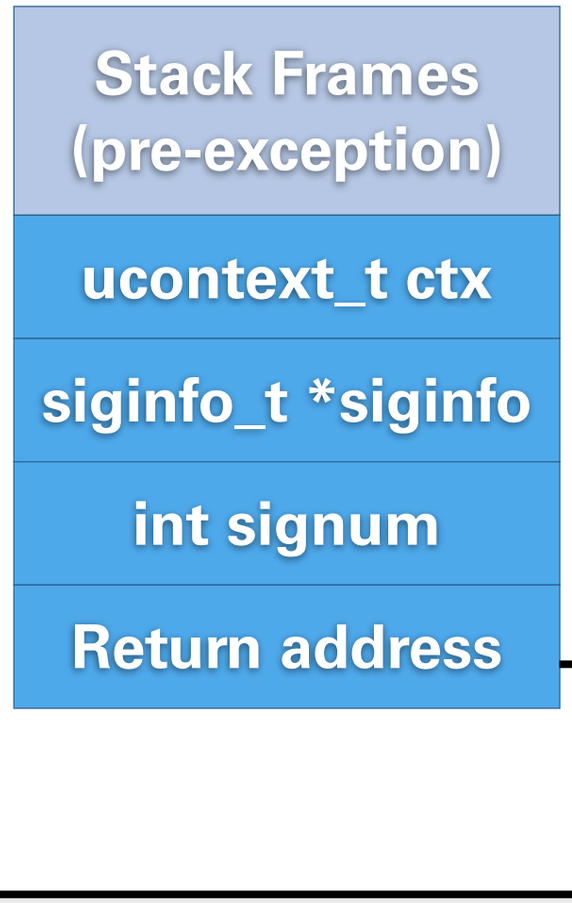
SIGNALS: L4RE

- Dedicated thread **E** handles exceptions and timers
- **E** is exception handler of thread **T**
- Exceptions in **T** are reflected to **E**
- If app configured signal handler:
  - **E** sets up signal handler context
  - **E** resets **T**'s program counter to start of signal handler
  - **T** executes signal handler, returns
- If possible, **E** restarts **T** where it had been interrupted



SIGNALS: MECHANICS

- **E**: handles exceptions:
  - Set up signal handler context:
    - Save **T**'s context
    - Push pointer to siginfo_t, signal number
    - Push address of return trap
  - **`l4_utcb_exc_pc_set(ctx, handler)`**
- **T**: execute signal handler, „returns“ to trap
- **E**: resume thread after signal:
  - Exception generated, reflected to E
  - Detects return by looking at T's exception PC
  - Restore T's context saved on stack, resume




```
void libc_be_sig_return_trap()
{
  /* trap, cause exception */
}
```

SIGNALS: SUMMARY

- Basic mechanism for Fiasco.OC + L4Re:
  - Exceptions are mapped to IPC messages
  - E waits for exception IPCs in server loop
- Timers implemented as IPC timeouts:
  - **`sigaction()`** / **`setitimer()`** called by **T**
  - **T** communicates time to wait to **E**
  - **E** waits for IPC timeout
  - **E** raises exception in T to deliver **`SIGALRM`**

I/O SUPPORT?

What is needed for file I/O?

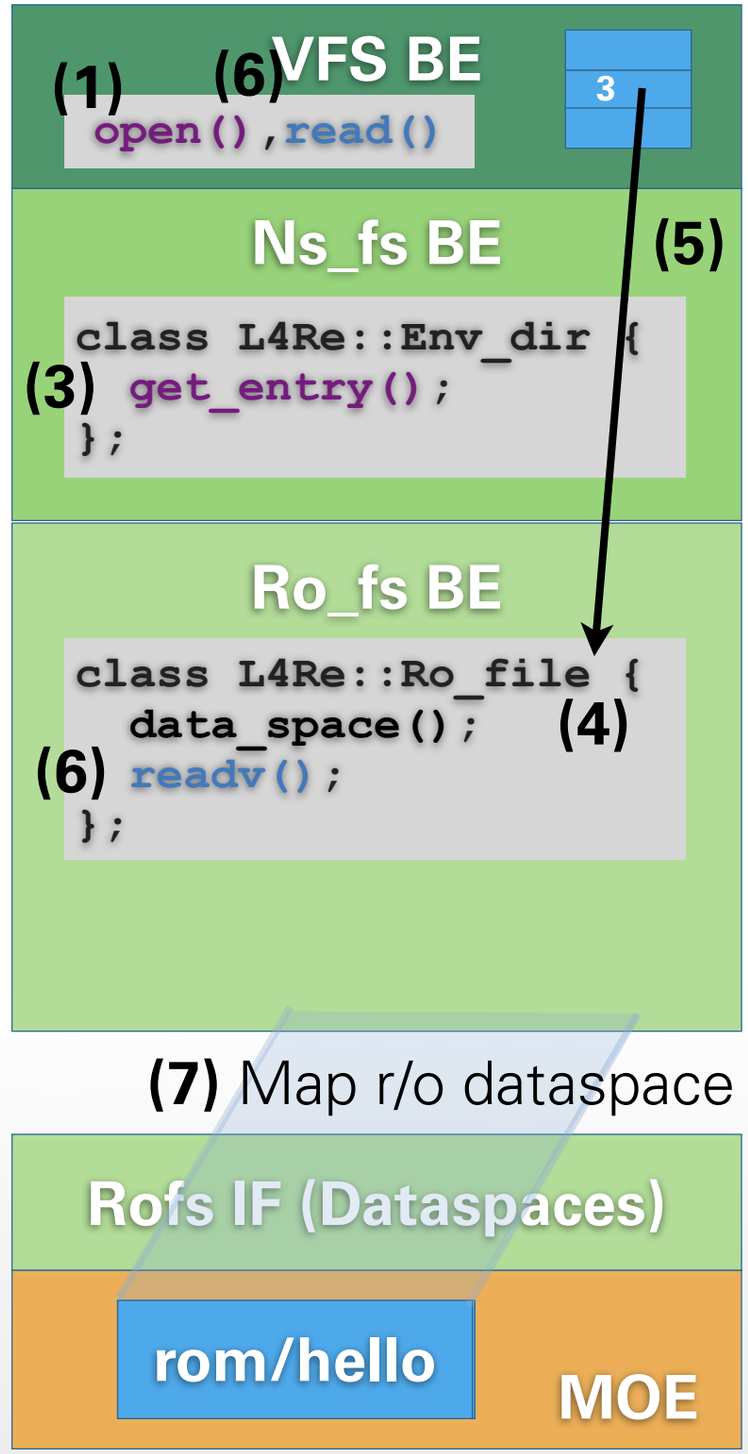
- fprintf() support: easy, just replace write()
- Minimalist backend can output text

```
#include <unistd.h>
#include <errno.h>
#include <l4/sys/kdebug.h>

int write(int fd, const void *buf, size_t count) __THROW
{
  /* just accept write to stdout and stderr */
  if ((fd == STDOUT_FILENO) || (fd == STDERR_FILENO))
    {
      l4kdb_outnstring((const char*)buf, count);
      return count;
    }
  /* writes to other fds shall fail fast */
  errno = EBADF;
  return -1;
}
```

ROM FILE SYSTEM

- (1) Application calls open(„rom/hello“)
- (2) VFS traverses mount tree, finds Ns_fs mounted at „rom“
- (3) VFS asks Ns_fs to provide a file for name „hello“, Ns_fs calls its get_entry() method
- (4) Ns_fs::get_entry() creates new Ro_file object from read-only dataspace provided by MOE
- (5) VFS registers file handle for Ro_file object
- (6) Application calls read(): ends in Ro_file::readv()
- (7) Ro_file::readv() attaches dataspace, copies requested data into read buffer



POSIX: SUMMARY

- L4Re offers significant part of POSIX APIs
  - C library: strcpy(), ...
  - Dynamic memory allocation:
    - malloc(), free(), mmap(), ...
      - Based on L4Re dataspaces
  - Threads, synchronization: Pthread
  - Signal handling
  - I/O support: files, terminal, time, (sockets)
- POSIX is enabler: sqlite, Cairo, SDL, shell, ...

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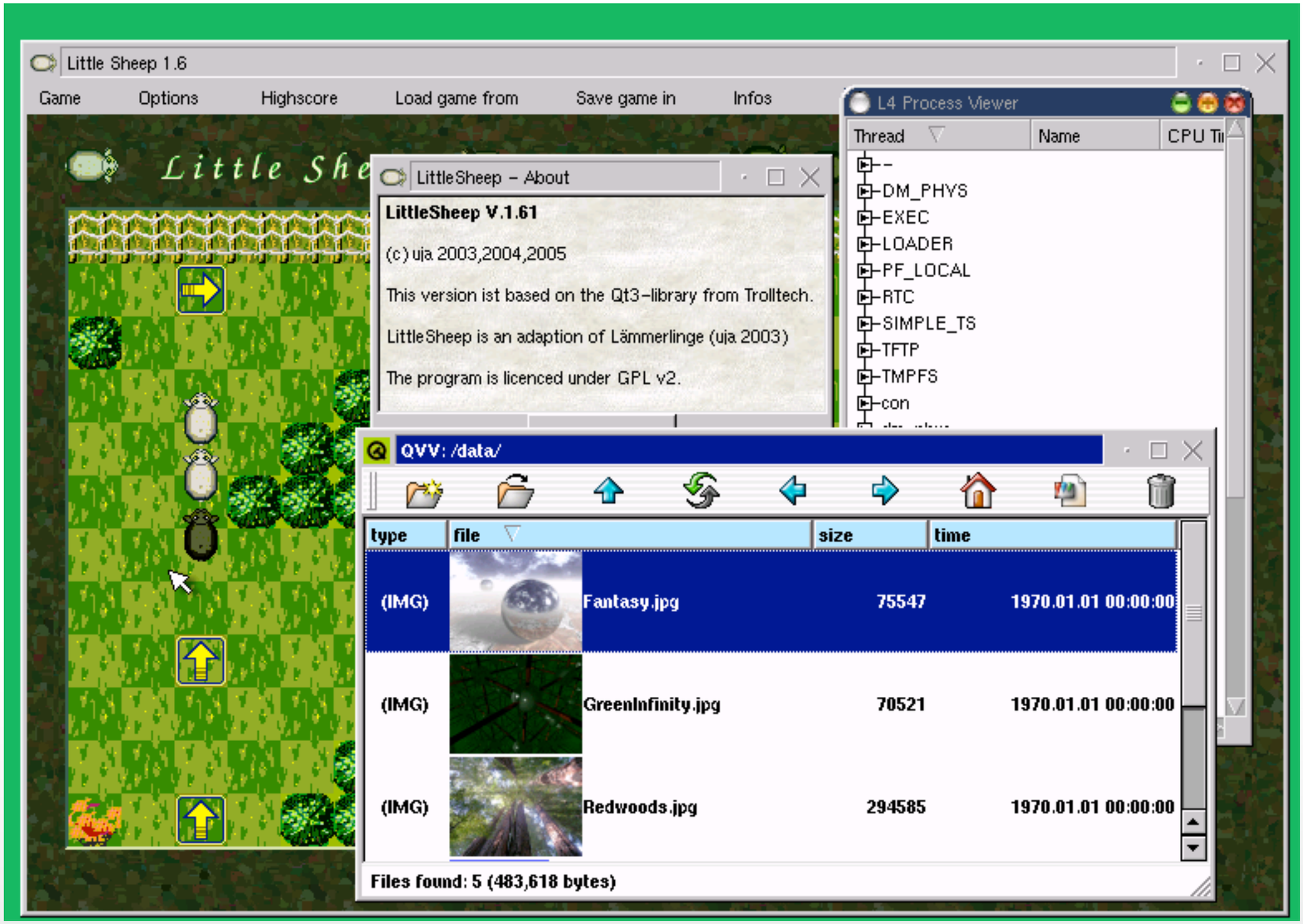
APPLICATION-LEVEL VIRTUALIZATION

RICH FRAMEWORKS

- POSIX is limited to basic OS abstractions
  - No graphics, GUI support
  - No audio support
- Examples for more powerful APIs:
  - SDL „Simple Direct Media Layer“:
    - Multimedia applications and games
  - Qt toolkit:
    - Rich GUIs with tool support
    - Fairly complete OS abstractions

SOFTWARE ON L4

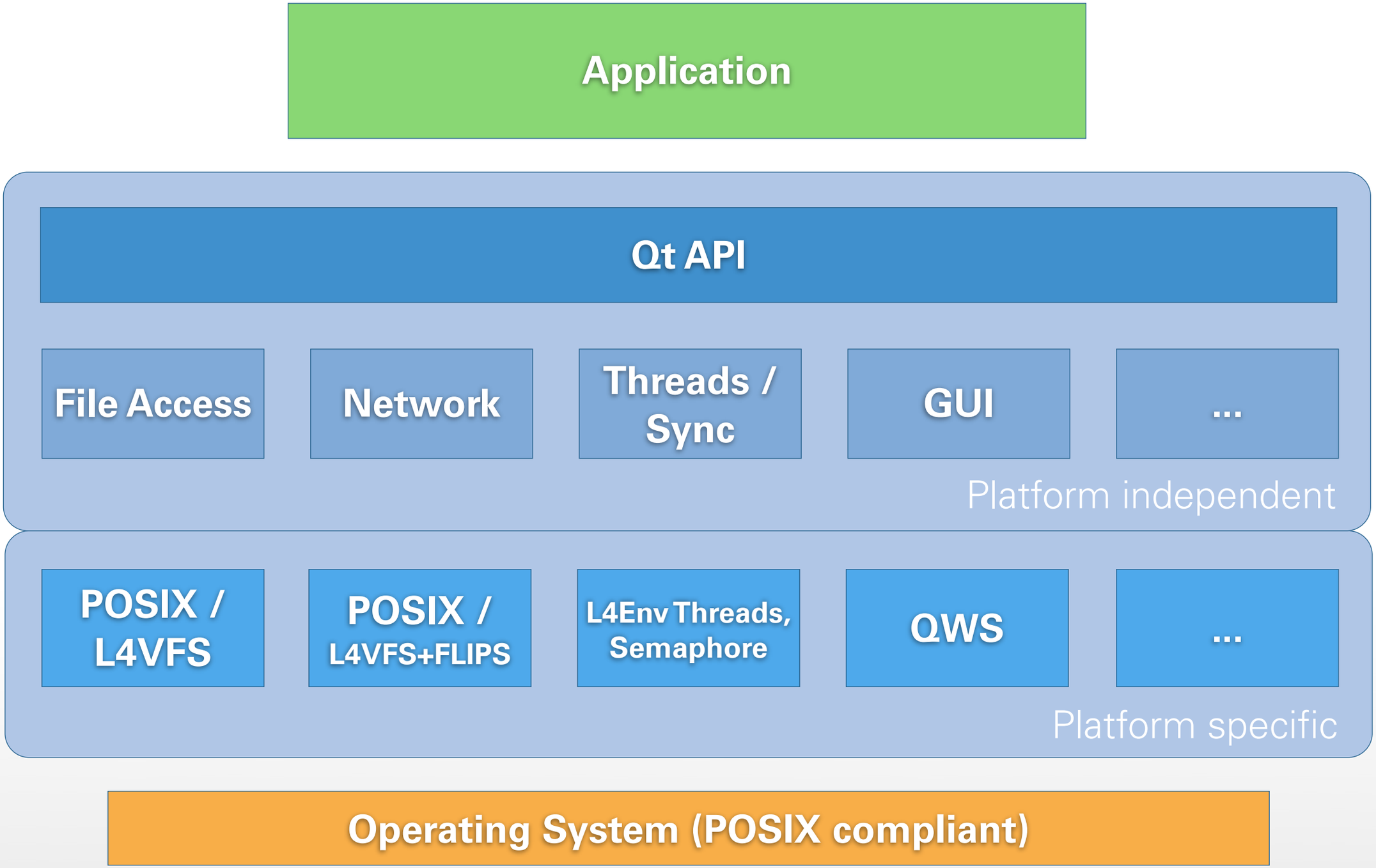
SOFTWARE ON L4



QT TOOLKIT

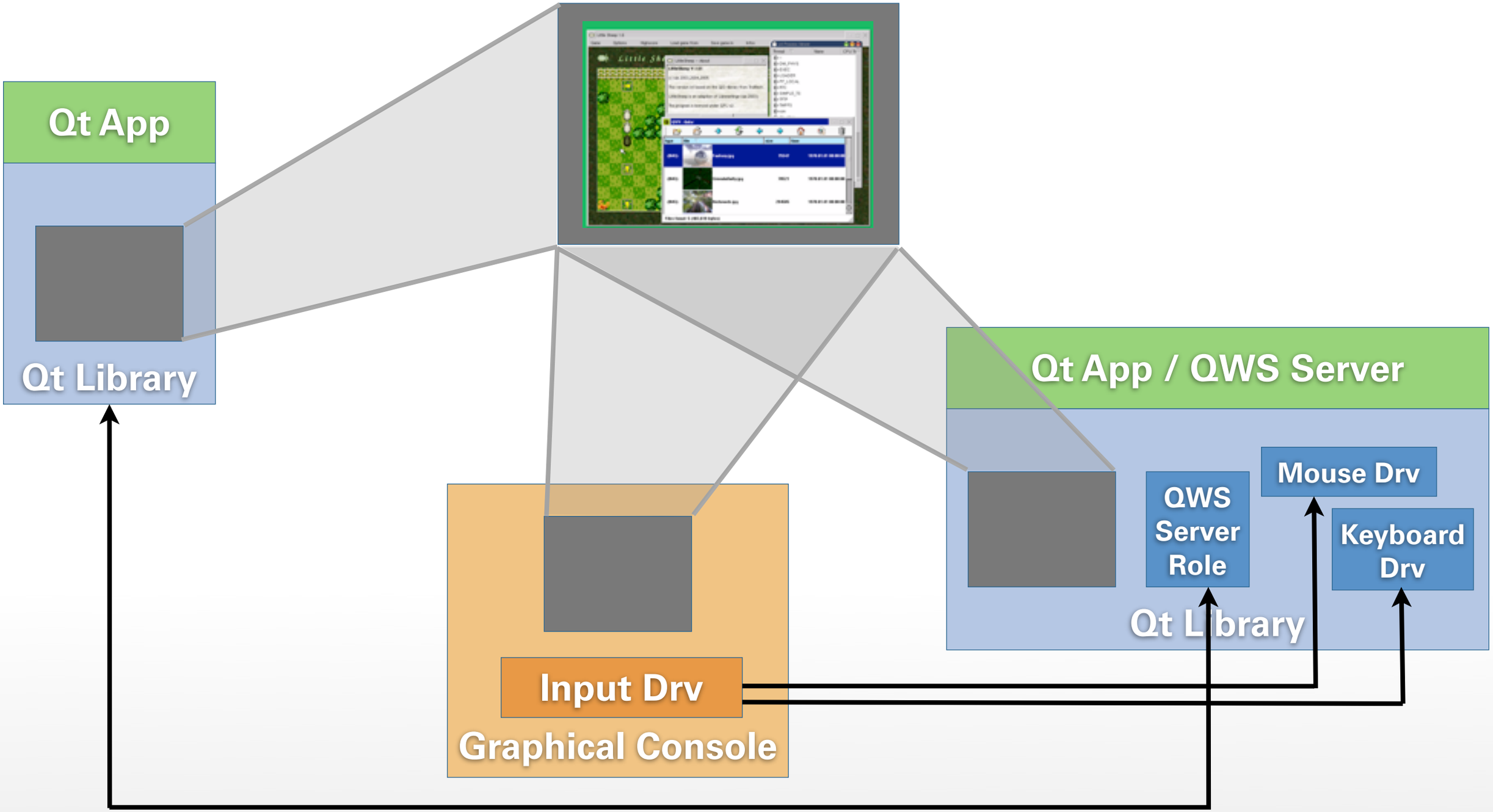
- **Qt** is a multi-platform toolkit library
- Compile & run same application on multiple platforms:
  - UNIX/X11, Embedded Linux
  - Windows, Mac OS X
  - Also ported to *L4Env*, *L4Re*, *Genode*
- **Qt/L4Env** based on Qt3 for Embedded Linux:
  - Brings its own windowing system
  - Relies on POSIX-like OS

QT/L4ENV PORT



DEMO

QT/L4ENV: MECHANICS



QT/L4ENV: FEATURES

- Thanks to POSIX APIs available on L4:
  - Complete Qt GUI framework
  - Threads, synchronization
  - File access (L4VFS or L4Re VFS)
- Limited network access:
  - L4Env: basic functionality with L4VFS IP stack „FLIPS“
  - L4Re: ???
- Tool support

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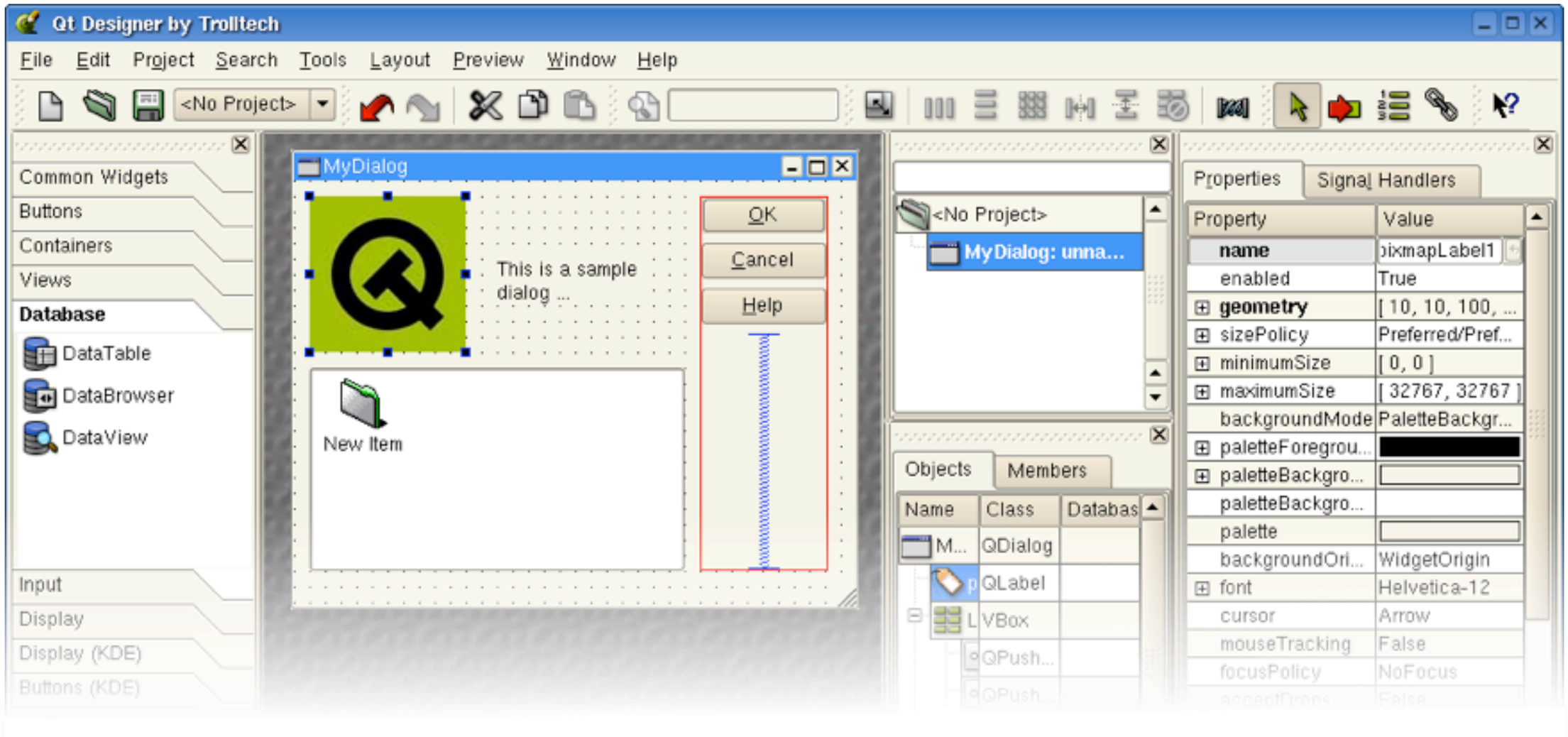
QT DESIGNER



- Tools: Qt Designer, UI compiler (uic), moc
- Test Applications (or parts of them) on Linux

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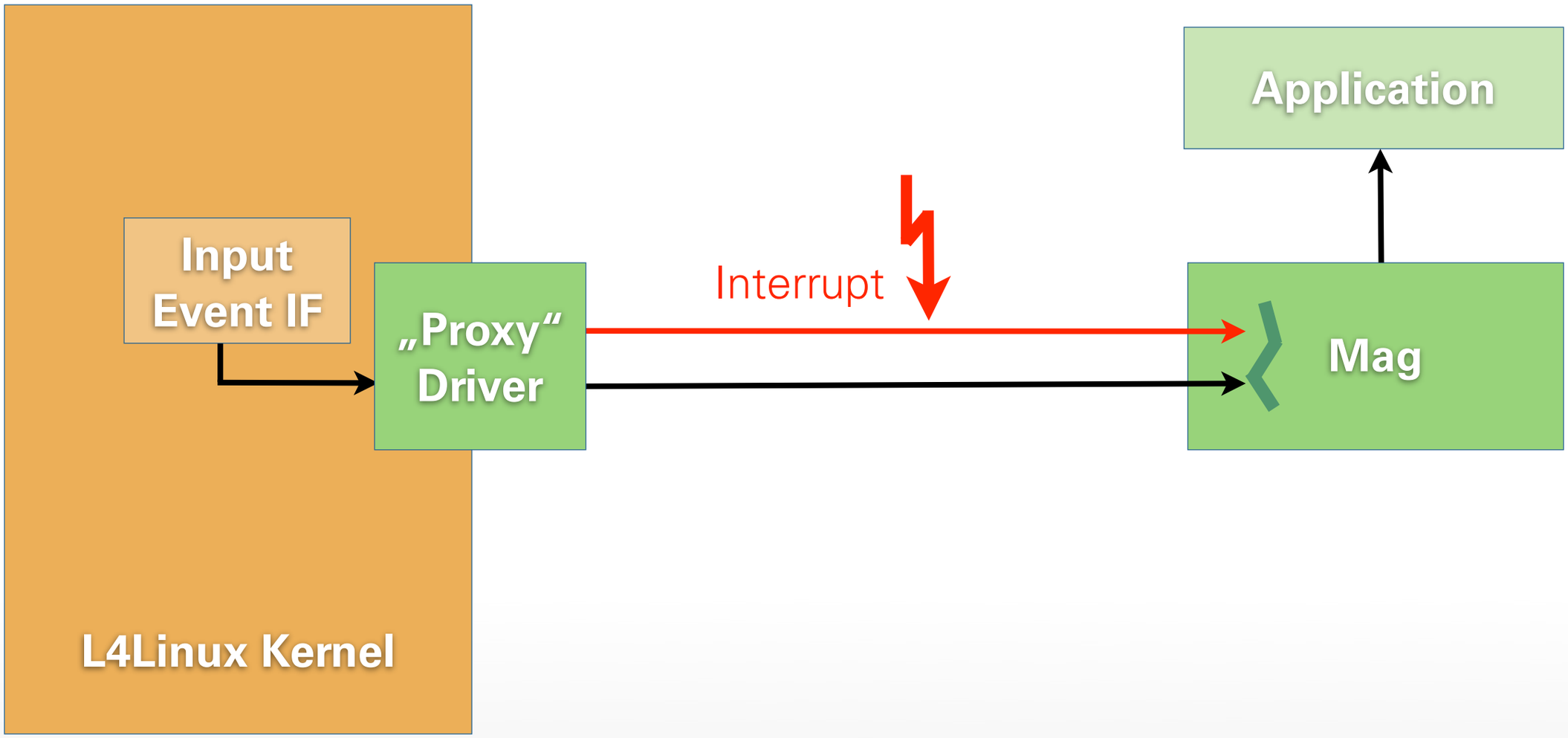
LEGACY OPERATING SYSTEM AS A TOOLBOX

LINUX TOOLBOX

- Applications are nice, but there‘s more ...
- Legacy OSes have lots of:
  - Device drivers
  - Protocol stacks
  - File systems
- Reuse drivers in natural environment
  - Also see paper: *„Unmodified Device Driver Reuse and Improved System Dependability via Virtual Machines“* , by LeVasseur, Uhlig, Stoess, Götz)
- L4Linux:
  - **Hybrid applications:** access legacy OS + L4Re
  - **In-kernel support:** bridge Linux services to L4Re

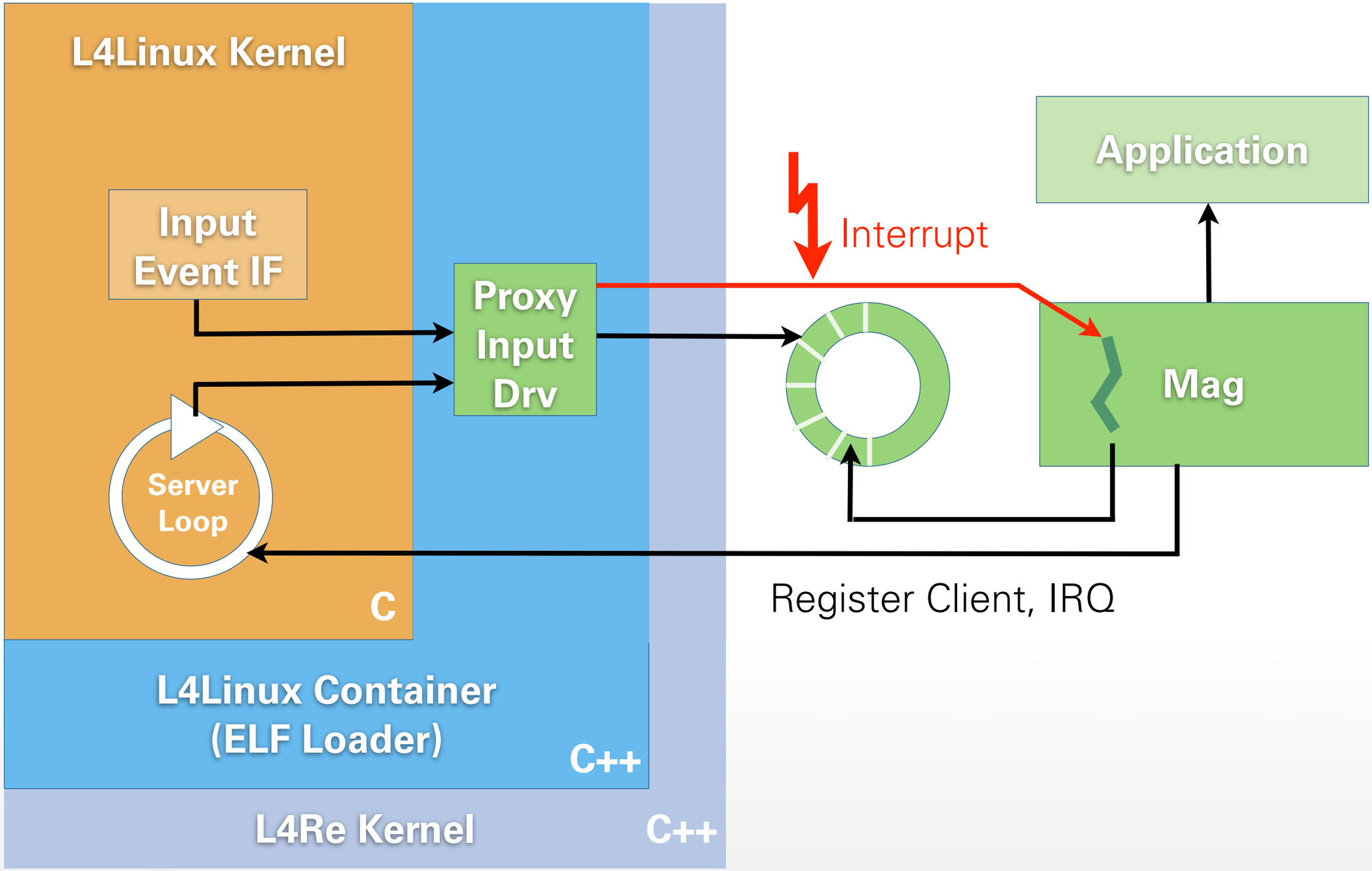
GENERAL IDEA



ACCESS L4LINUX

- L4Linux has drivers
- L4Re has great infrastructure for servers:
  - IPC framework
  - Generic server loop
- **Problem:** C vs. C++, calling conventions
- **Bridge:** allow calls from Linux to L4Re
  - L4Re underneath L4Linux export C functions
  - L4Linux kernel module calls them

INPUT DRIVER



WHAT'S NEXT?

- **Later today:** Paper reading exercise
- **December 21:** Lecture *„Security Intro“*

References

- [1] Carsten Weinhold: **„Portierung von Qt auf DROPS“,** TU Dresden, Großer Beleg 2005, *http://os.inf.tu-dresden.de/paper_ps/weinhold-beleg.pdf*
- [2] Resources on POSIX standard: *http://standards.ieee.org/regauth/posix/*
- [3] **„Unmodified Device Driver Reuse and Improved System Dependability via Virtual Machines“** , by J. LeVasseur, V. Uhlig, J. Stoess, S. Götz, OSDI 2004