Introducing kernel-agnostic Genode executables

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Outline

1. Kernel diversity - What’s the appeal?

2. Bridging the gap between kernels
   - Notion of components
   - Raising the level of abstraction of IPC
   - Virtual-memory management
   - Custom tooling

3. From a uniform API to binary compatibility

4. Future prospects
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4. Future prospects
Despair-driven development

Security came into focus of the L4 community in 2003:

- Capability-based security

Genode started as the designated user land of NOVA:

- Problem: NOVA did not exist
- How to build a user land for a non-existing kernel?

Planning in terms of interim solutions:

- Weak assumptions about the kernel

Approach:

- Target two existing kernels at once
- Opposite ends of a spectrum: Linux and L4/Fiasco
- If it works on those, it should be portable to NOVA

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Reassuring experiences

- Boosting our development
  - Quick development-test cycle on GNU/Linux
  - Debugging via GDB, strace
  - Kernel debugger on L4/Fiasco
- Stressing the robustness of our code
  - Different kernels expose subtle problems
  - Cross-correlating bugs and performance problems
- Getting clarity of application-level requirements

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- Getting clarity of application-level requirements
Benefiting from a high diversity of kernels

Kernels differ in many respects:

- Hardware-platform support

- Leveraged hardware features
  *Virtualization, IOMMU, SMP, TrustZone*

- Performance, security, scheduling

- Implementation, License

- Community
Surprisingly little kernel-specific code!

<table>
<thead>
<tr>
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</tr>
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<td>3,300</td>
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<tr>
<td>repos/base-hw/</td>
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</tbody>
</table>

→ manageable
Emergence of a vision

What POSIX is for monolithic OSes, Genode may become for microkernel-based OSes.

→ Deliberate cultivation of cross-kernel interoperability
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   - Notion of components
   - Raising the level of abstraction of IPC
   - Virtual-memory management
   - Custom tooling

3. From a uniform API to binary compatibility

4. Future prospects
Overcoming prevalent assumptions

Application requirements are rather mysterious

Preoccupation with scalability and performance concerns

POSIX (?)

Thread-local storage (?)

We disregarded those premises (liberating!)

...to be considered later.

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Application requirements are rather mysterious

- Preoccupation with scalability and performance concerns
- POSIX (?)
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Holistic architecture

Clean-slate design
Traditional: Tight user-kernel interplay
Hiding the construction of components

**Traditional:** Tight user-kernel interplay

**Interesting at application level:**

- Defining the executable to load
  \( \rightarrow ROM \text{ dataspace} \)
- Exercising control over the new protection domain
  \( \rightarrow Parent\text{-}child RPC interface \)
Hiding the construction of components

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Approach: Satisfy those requirements, hide “loading” mechanics
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Traditional: IPC involves kernel details

Microkernel IPC ridden with technicalities and jargon

thread IDs, task IDs, portals, message registers, message tags, message dopes, message-buffer layouts, UTCBs, MTDs, hot spots, CRDs, receive windows, badges, reply capabilities, flex pages, string items, timeouts, short IPC vs. long IPC
Microkernel IPC ridden with technicalities and jargon

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IDL compilers supposedly hide those details. But they don’t.
IPC from the application’s perspective

Genode’s API level:

- Consistent and simple nomenclature (client, server, session, RPC object, capability)
- Synchronous RPC in the strictest sense (RPC stub code generated by C++ templates, no IDL)
- Capabilities instead of global name spaces (lifetime managed as C++ smart pointer)
- Asynchronous notifications without payload (like interrupts)

→ no bit fiddling, “optimizations”
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Traditional:
- Page-fault protocol (L4)
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- Page-fault protocol (L4)
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Dataspace: Memory object referred by a capability
- Owner = creator
- Created via the root of the component tree
- Can be attached to a component’s local address space
- Can be shared with others by delegating the capability
  → shared memory
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Using a particular kernel

Technical aspects:
- Source distribution
- Tooling (configuration, build system, tool chain, custom scripts)
- Kernel bindings
- Intrinsic user-level dependencies (ties to a particular user land)
- System integration and configuration
  - Booting, logging, debugging, work flows (e.g., menu.lst)

→ Exploration/education costs

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Relieving the user from those technicalities

Introducing kernel-agnostic Genode executables
Relieving the user from those technicalities

Custom tooling

- Bullet-proof integration of 3rd-party code
  → *ports mechanism*

- Kernel-agnostic system-scenario descriptions
  → *run scripts*

- Unified tool chain
  → *blessed bare-metal C++ runtime*
The choice of the kernel is almost transparent.
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How the kernel taints the user land

1. Inclusion of kernel headers
   ▶ System-call bindings
   ▶ Kernel-specific types (IDs, IPC structures, error codes)
   ▶ Utilities

2. Component code that issues system calls
   ▶ IPC
   ▶ Multi-threading, synchronization
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   ▶ Hardware access
   ▶ Kernel-object creation/destruction

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Decoupling the user land from the kernel

1. Clean Genode’s API headers from kernel-specific artifacts
   - Uniform capability representation
   - Generic IPC message-buffer layout
   - Thread manipulation, synchronization
   - Hide address-space layout constraints

2. Galvanic separation of kernel-specific from application code
   - distinct ELF objects

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Key element: Dynamic linker

The dynamic linker’s split personality:

Compile time: shared library
▶ Linked to components
▶ Satisfies dependencies on the Genode API at link time

Runtime: static binary
▶ Lives inside the component
▶ Obtains and bootstraps the kernel-agnostic executable
▶ Resolves references to the Genode API with itself
▶ Exposes the Genode API as its library interface
▶ Loads and initializes shared libraries

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*free-standing Genode API → generic ABI of the dynamic linker*
Genode’s application binary interface (ABI)

ABI definition:

- Symbol names, types, and meta data
- Extracted from the concrete dynamic linker instance
- Cleaned from redundancies
  - Undefined symbols
  - Weak C++ symbols
    - (template instances, inline functions, vtables, type infos)
- Cross-checked with all kernels
  - No inner-framework global symbols
  - A few kernel-specific parts remain

→ Genode ABI definition: 22 KiB
Goal: The same ABI across all supported architectures

(x86_32, x86_64, ARM, RISC-V)
Crossing CPU-architecture boundaries

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**Shudder:** Huge differences between x86_32 and x86_64
Life would be good without size_t

```c
size_t = __SIZE_TYPE__ (compiler-defined)
```
Life would be good without size_t

\[
\text{size}_t = \text{\_\_SIZE\_TYPE\_\_} \text{ (compiler-defined)}
\]
\[
\times86\_32: \text{\_\_SIZE\_TYPE\_\_} = \text{unsigned int}
\]
\[
\times86\_64: \text{\_\_SIZE\_TYPE\_\_} = \text{unsigned long}
\]
Life would be good without **size_t**

```c
size_t = __SIZE_TYPE__ (compiler-defined)

x86_32: __SIZE_TYPE__ = unsigned int
x86_64: __SIZE_TYPE__ = unsigned long

Mangled C++ symbols encode entire function signatures

**Example:** void Connection::upgrade_ram(size_t)

x86_32: _ZN10Connection11upgrade_ramEj
x86_64: _ZN10Connection11upgrade_ramEm
```
Life is (almost) good without size_t

No use of __SIZE_TYPE__ by Genode API:

- Genode::size_t defined as unsigned long
  → Genode ABI is architecture agnostic
- Remaining problem: libc uses compiler-defined size_t
- Fine for C code (symbol == function name w/o arguments)
- Problem with libc-depending C++ code (like Qt5)

→ Solution 1: architecture-dependent ABIs
→ Solution 2: tweak the compiler
Generalization of the ABI mechanism

Build system support:
- ABI definition is translated to an assembly file (almost architecture independent)
- Assembly file is compiled/linked into an `.abi.so` file (shared library that contains only symbols but no code)
- Library-using targets are linked against the `.abi.so` file instead of the real library

ABI formalism for arbitrary libraries!
- merely add an ABI definition for a library → Targets can be built without the libraries they depend on.

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\(\rightarrow\) Targets can be built without the libraries they depend on.
Immediate benefits

Build directory used to depend on kernel and hardware platform.
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**New unified build directories:**

- Depend only on hardware platform
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**New unified build directories:**

- Depend only on hardware platform
- Kernel-agnostic targets are linked dynamically *(almost all components)*
- Kernel-specific targets are named after the kernel *(ld-nova.lib.so, core-nova, timer driver)*

→ *build results can peacefully coexist*
Immediate benefits

Build directory used to depend on kernel and hardware platform.

**New unified build directories:**

- Depend only on hardware platform
- Kernel-agnostic targets are linked dynamically (almost all components)
- Kernel-specific targets are named after the kernel (ld-nova.lib.so, core-nova, timer driver)
  \[ \text{build results can peacefully coexist} \]
- Choice of kernel not before running a scenario:
  \[ \text{make run/demo KERNEL=nova} \]
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Package management

- Distinction between source and API/ABI packages
  → *Loose coupling of packages*
- Binary packages independent of the used kernel
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Multiple levels of API/ABI stability
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Multiple levels of API/ABI stability

Two orthogonal directions

1. Successive hardening of the foundation, transparent to users
2. Scaling the software stack with a fixed target
Unique solutions, enabled by Free Software

Introducing kernel-agnostic Genode executables
Shaping the entire vertical software stack:

- Tool chain ↔ Work-flow automation ↔ Quality assurance
- Build system ↔ Source-code management ↔ Package management
- Dynamic linker (*cross-kernel binary compatibility*)
- C runtime, C++ runtime (*encapsulating legacies*)
- VFS infrastructure (*component-level customizations*)
- Init and system configuration (*session routing*)
- Genode ABI and API (*enforcing a safe C++ dialect*)
- Kernel (*base-hw, scheduling, kernel-resource management*)
- Component interfaces (*multi-component applications*)
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→ Cross-pollination between different levels
→ **Simple and holistic solutions!**
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Thank you

Genode OS Framework
https://genode.org

Genode Labs GmbH
https://www.genode-labs.com

Source code at GitHub
https://github.com/genodelabs/genode