

RIOT Hands-on Tutorial

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Starting the RIOT

Preparations

For links go to <https://github.com/RIOT-OS/Tutorials>

Quick Setup (Using a Virtual Machine)

- ▶ Install and set up git
- ▶ Install VirtualBox & VirtualBox Extension Pack
- ▶ Install Vagrant
- ▶ `git clone --recursive https://github.com/RIOT-OS/Tutorials`
- ▶ go to RIOT root directory: `cd Tutorials/RIOT`
- ▶ Run the Vagrant RIOT Setup
- ▶ go back Tutorial directory `cd ..`

Recommended Setup (Without Using a VM)

- ▶ Install and set up git
- ▶ Install the build-essential packet (make, gcc etc.). This varies based on the operating system in use.
- ▶ Install Native dependencies
- ▶ Install OpenOCD
- ▶ Install GCC Arm Embedded Toolchain
- ▶ On OS X: install Tuntap for OS X
- ▶ additional tweaks necessary to work with the targeted hardware (ATSAMR21)
- ▶ Install netcat with IPv6 support (if necessary)
`sudo apt-get install netcat-openbsd`
- ▶ `git clone --recursive https://github.com/RIOT-OS/Tutorials`

Running RIOT

- ▶ Applications in RIOT consist at minimum of
 - ▶ a Makefile
 - ▶ a C-file, containing a `main()` function
- ▶ To see the code go to the task-01 directory:

```
cd task-01
```

```
ls
```

Your first application – The Makefile

```
# name of your application
```

```
APPLICATION = Task01
```

```
# If no BOARD is found in the environment, use this default:
```

```
BOARD ?= native
```

```
# This has to be the absolute path to the RIOT base directory:
```

```
RIOTBASE ?= $(CURDIR)/../../RIOT
```

```
# Comment this out to disable code in RIOT that does safety checking
```

```
# which is not needed in a production environment but helps in the
```

```
# development process:
```

```
CFLAGS += -DDEVELHELP
```

```
# Change this to 0 show compiler invocation lines by default:
```

```
QUIET ?= 1
```

```
# Modules to include:
```

```
USEMODULE += shell
```

```
USEMODULE += shell_commands
```

```
USEMODULE += ps
```

```
include $(RIOTBASE)/Makefile.include
```

Your first application – The C-file

```
#include <stdio.h>
#include <string.h>

#include "shell.h"

int main(void)
{
    puts("This is Task-01");

    char line_buf[SHELL_DEFAULT_BUFSIZE];
    shell_run(NULL, line_buf, SHELL_DEFAULT_BUFSIZE);

    return 0;
}
```

Task 1.1: Run your first application as Linux process

1. Compile & run on native: `make all term`
2. Type `help`
3. Type `ps`
4. Modify your application:
 - ▶ Add a `printf("This application runs on %s", RIOT_BOARD);` *before* `shell_run()`
 - ▶ Recompile and restart `make all term`
 - ▶ Look at the result

Task 1.2: Run your first application on real hardware

1. Compile, flash and run on samr21-xpro
BOARD=samr21-xpro make all flash term
(or other BOARD if available)
2. Verify output of RIOT_BOARD

Custom shell commands

Writing a shell handler

- ▶ Shell command handlers in RIOT are functions with signature

```
int cmd_handler(int argc, char **argv);
```

- ▶ argv: array of strings of arguments to the command

```
print hello world    # argv == {"hello", "world"}
```

- ▶ argc: length of argv

Adding a shell handler to the shell

- ▶ Shell commands need to be added manually to the shell on initialization

```
#include "shell.h"
```

```
static const shell_command_t shell_commands[] = {  
    { "command name", "command description", cmd_handler },  
    { NULL, NULL, NULL }  
};
```

```
/* ... */  
    shell_run(commands, line_buf, SHELL_DEFAULT_BUFSIZE)  
/* ... */
```

Task 2.1 – A simple echo command handler

- ▶ Go to task-02 directory (`cd ../task-02`)
- ▶ Write a simple echo command handler in `main.c`:
 - ▶ First argument to the echo command handler shall be printed to output

```
> echo "Hello World"
Hello World
> echo foobar
foobar
```

Task 2.2 – Control the hardware

- ▶ `board.h` defines a macro `LED0_TOGGLE` to toggle the primary LED on the board.
- ▶ Write a command handler `toggle` in `main.c` that toggles the primary LED on the board

Multithreading

Threads in RIOT

- ▶ Threads in RIOT are functions with signature

```
void *thread_handler(void *arg);
```

- ▶ Use `thread_create()` from `thread.h` to start:

```
pid = thread_create(stack, sizeof(stack),  
                    THREAD_PRIORITY_MAIN - 1,  
                    THREAD_CREATE_STACKTEST,  
                    thread_handler,  
                    NULL, "thread");
```

RIOT kernel primer

Scheduler:

- ▶ Tick-less scheduling policy ($O(1)$):
 - ▶ Highest priority thread runs until finished or blocked
 - ▶ ISR can preempt any thread at all time
 - ▶ If all threads are blocked or finished:
 - ▶ Special IDLE thread is run
 - ▶ Goes into low-power mode

IPC (not important for the following task):

- ▶ Synchronous (default) and asynchronous (optional, by IPC queue initialization)

Task 3.1 – Start a thread

- ▶ Go to task-03 directory (`cd ../task-03`)
- ▶ Open `main.c`
- ▶ Reminder:

```
pid = thread_create(stack, sizeof(stack),  
                    THREAD_PRIORITY_MAIN - 1,  
                    THREAD_CREATE_STACKTEST,  
                    thread_handler,  
                    NULL, "thread");
```

- ▶ Start the thread "thread" from within `main()`
- ▶ Run the application on native: `make all term`
- ▶ Check your output, it should read: `I'm in "thread" now`

Timers

xtimer primer

- ▶ xtimer is the high level API of RIOT to multiplex hardware timers
- ▶ Examples for functionality:
 - ▶ `xtimer_now()` to get current system time in microseconds
 - ▶ `xtimer_sleep(sec)` to sleep sec seconds
 - ▶ `xtimer_usleep(usec)` to sleep usec microseconds

Task 4.1 – Use xtimer

- ▶ Reminder: Functions `xtimer_now()`, `xtimer_sleep()`, and `xtimer_usleep()` were introduced
- ▶ Go to task-04 directory (`cd ../task-04`)
- ▶ Note the inclusion of `xtimer` in Makefile

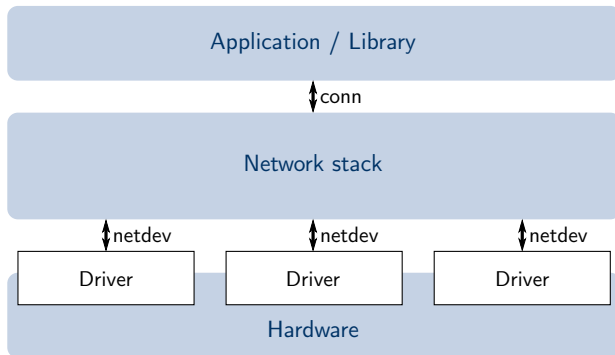
```
USEMODULE += xtimer
```

- ▶ Create a thread in `main.c` that prints the current system time every 2 seconds
- ▶ Check the existence of the thread with `ps` shell command

General networking architecture

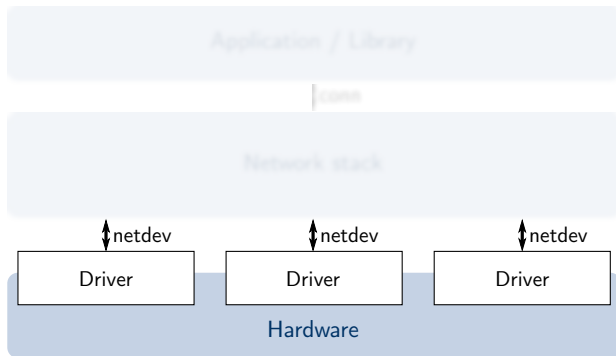
RIOT's Networking architecture

- Designed to integrate any network stack into RIOT



RIOT's Networking architecture

- ▶ Designed to integrate any network stack into RIOT



Including the network device driver

- ▶ Go to task-05 directory (cd ../task-05)
- ▶ Note inclusion of netdev modules in Makefile

```
USEMODULE += gnrc_netdev_default
```

```
USEMODULE += auto_init_gnrc_netif
```


Virtual network interface on native

- ▶ Use tapsetup script in RIOT repository:

```
../../RIOT/dist/tools/tapsetup/tapsetup -c 2
```

- ▶ Creates
 - ▶ Two TAP interfaces tap0 and tap1 and
 - ▶ A bridge between them (tapbr0 on Linux, bridge0 on OSX)
- ▶ Check with ifconfig or ip link!

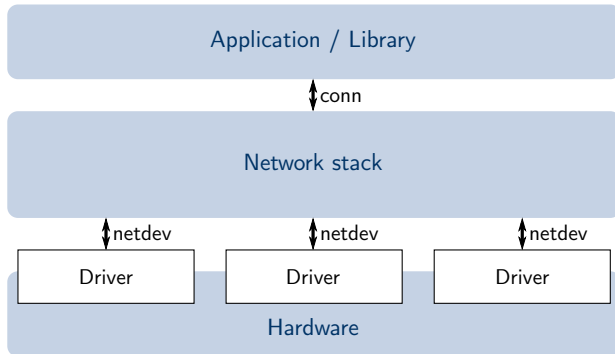
Task 5.1 – Your first networking application

- ▶ Run the application on native: `PORT=tap0 make all term`
- ▶ Type `help`
- ▶ Run a second instance with `PORT=tap1 make all term`
- ▶ Type `ifconfig` on both to get hardware address and interface number
- ▶ Use `txtsnd` command to exchange messages between the two instances

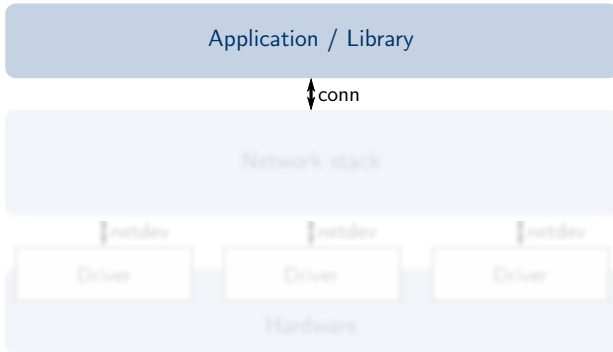
Task 5.2 – Use your application on real hardware

- ▶ Compile, flash, and run on the board `BOARD=samr21-xpro`
`make all flash term`
- ▶ Type `ifconfig` to get your hardware addresses
- ▶ Use `txtsnd` to send one of your neighbors a friendly message

RIOT's Networking architecture



RIOT's Networking architecture



conn

- ▶ collection of unified connectivity APIs to the transport layer
- ▶ What's the problem with POSIX sockets?
 - ▶ too generic for most use-cases
 - ▶ numerical file descriptors (internal storage of state required)
 - ▶ in general: too complex for usage, too complex for porting
- ▶ protocol-specific APIs:
 - ▶ `conn_ip` (raw IP)
 - ▶ `conn_udp` (UDP)
 - ▶ `conn_tcp` (TCP)
 - ▶ ...
- ▶ both IPv4 and IPv6 supported

Task 6.1 – Use UDP for messaging

- ▶ Go to task-06 directory `cd ../task-06`
- ▶ Note the addition of `gnrc_conn_udp` to Makefile
- ▶ `udp.c` utilizes `conn_udp_sendto()` and `conn_udp_recvfrom()` to exchange UDP packets
- ▶ Compile and run on two native instances
- ▶ Type `help`
- ▶ Use `udps 8888` to start a UDP server on port 8888 on first instance (check with `ps`)
- ▶ Use `ifconfig` to get link-local IPv6 address of first instance
- ▶ Send UDP packet from second instance using `udp` command to first instance

Task 6.2 – Communicate with Linux

- ▶ Compile and run a native instance
- ▶ Start a UDP server on port 8888 (using udps)
- ▶ Send a packet to RIOT from Linux using netcat

```
echo "hello" | nc -6u <RIOT-IPv6-addr>%tap0 8888
```

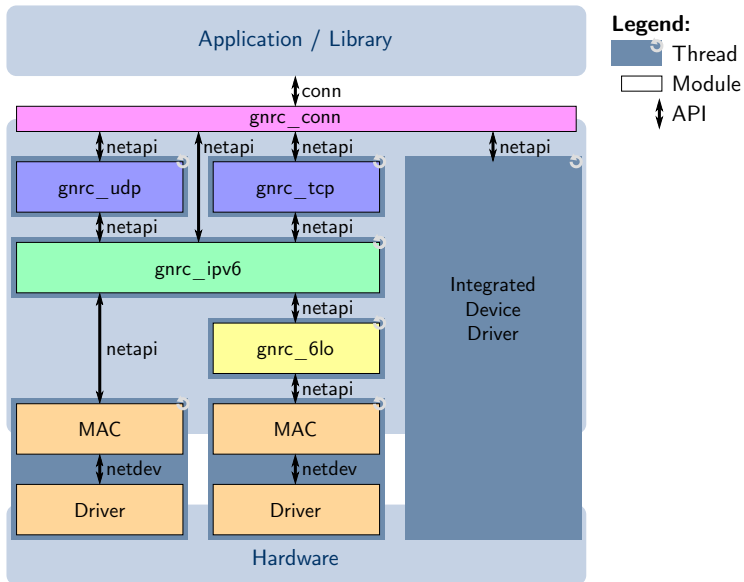
- ▶ Start a UDP server on Linux `nc -6lu 8888`
- ▶ Send a UDP packet from RIOT to Linux
`udp <tap0-IPv6-addr> 8888 hello`

Task 6.3 – Exchange UDP packets with your neighbors

- ▶ Compile, flash and run on the board `BOARD=samr21-xpro`
`make all flash term`
- ▶ Send and receive UDP messages to and from your neighbors
using `udp` and `udps`

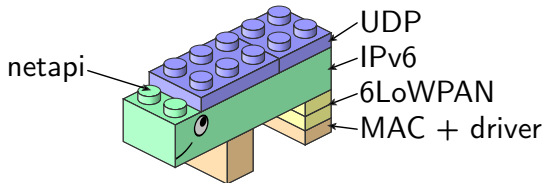
GNRC

The components of GNRC

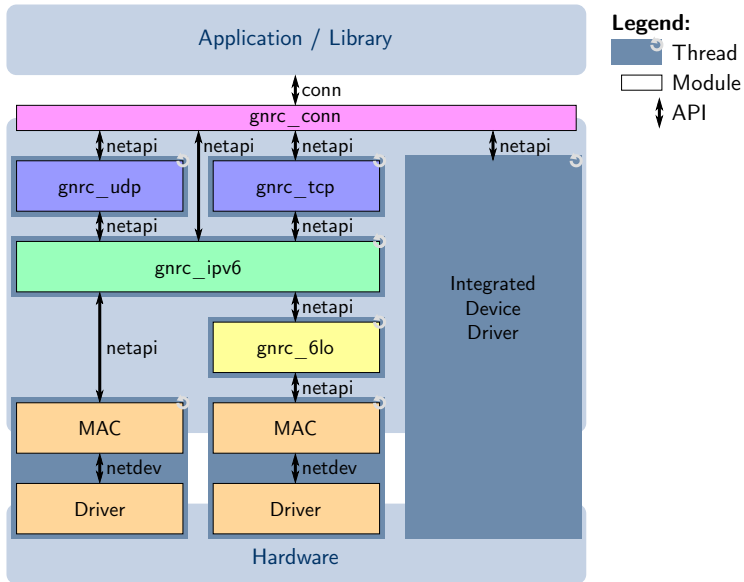


netapi

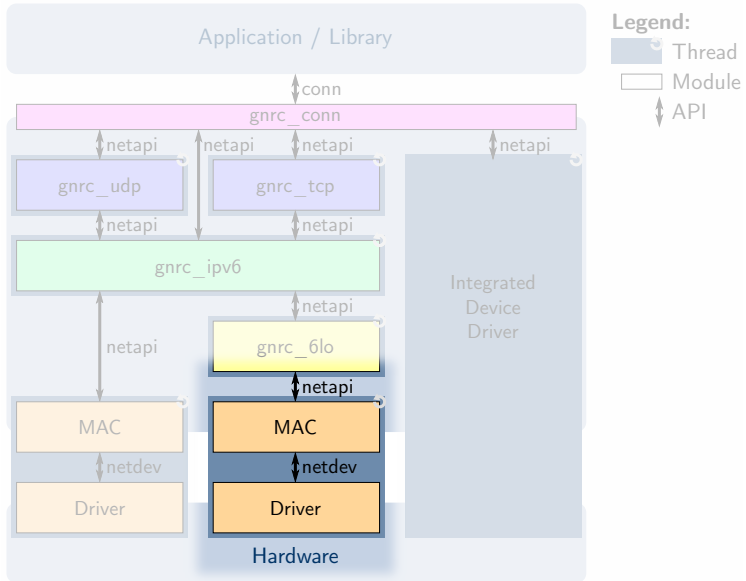
- ▶ Inter-modular API utilizing IPC
- ▶ Two asynchronous message types (don't expect reply) for data transfer:
 - ▶ GNRC_NETAPI_MSG_TYPE_SND: pass “down” the stack (send)
 - ▶ GNRC_NETAPI_MSG_TYPE_RCV: pass “up” the stack (receive)
- ▶ Two synchronous message types (expect reply) for option handling:
 - ▶ GNRC_NETAPI_MSG_TYPE_GET: get option value
 - ▶ GNRC_NETAPI_MSG_TYPE_SET: set option value
- ▶ Specification deliberately vague
⇒ implementations can make own preconditions on data



Network interfaces in GNRC (1)

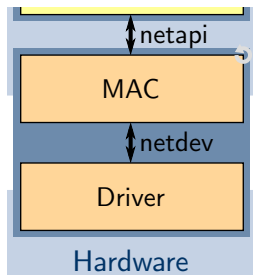


Network interfaces in GNRC (1)



Network interfaces in GNRC (2)

- ▶ `netapi`-capable thread as any other protocol implementation
- ▶ Implement MAC protocol
- ▶ Communication to driver via `netdev`
 - ⇐ timing requirements for e.g. TDMA-based MAC protocols



netreg

- ▶ How to know where to send netapi messages?

netreg

- ▶ How to know where to send netapi messages?
- ▶ Both protocol implementation and users can register to be interested in type + certain context (e.g. port in UDP)

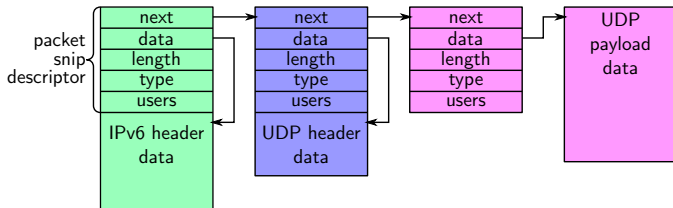
```
gnrc_netreg_t ipv6_handler = { NULL,  
                                GNRC_NETREG_DEMUX_CTX_ALL,  
                                ipv6_handler_pid};  
gnrc_netreg_register(GNRC_NETTYPE_IPV6, &ipv6_handler);
```

```
gnrc_netreg_t dns_handler = { NULL, PORT_DNS,  
                              dns_handler_pid};  
gnrc_netreg_register(GNRC_NETTYPE_UDP, &dns_handler);
```

⇒ Find handler for packets in registry

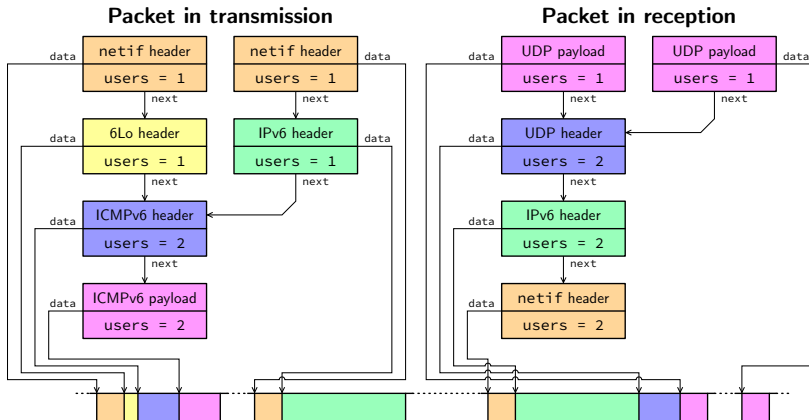
pktbuf

- ▶ Data packet stored in pktbuf
- ▶ Representation: list of variable-length “packet snips”
- ▶ Protocols can *mark* sections of data to create new snip
- ▶ Keeping track of referencing threads: reference counter users
 - ▶ If users == 0: packet removed from packet buffer
 - ▶ If users > 1 and write access requested: packet duplicated (*copy-on-write*)



pktbuf – keeping duplication minimal

- ▶ Only copy up to most *current* packet snip
 - ⇒ Packets become tree-like
 - ⇒ Reverse order for received packets to only have one pointer



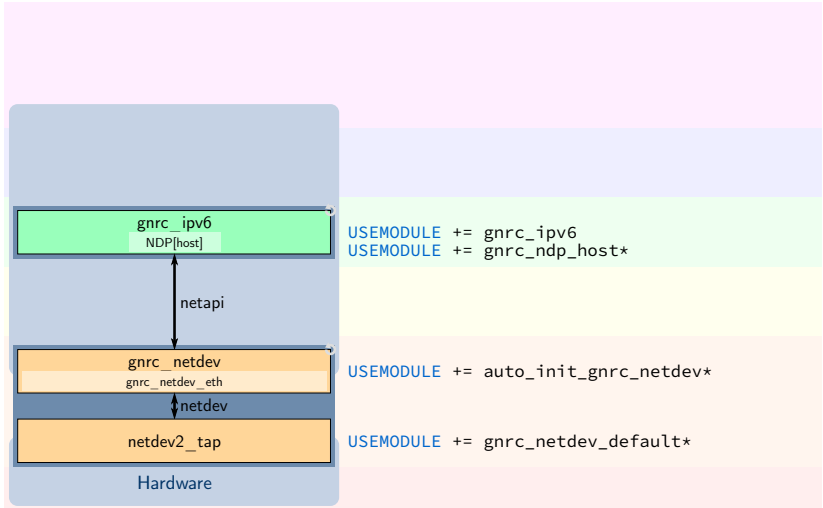
RIOT examples

The remaining slides utilize the RIOT examples:

```
cd ../RIOT/examples/  
ls
```

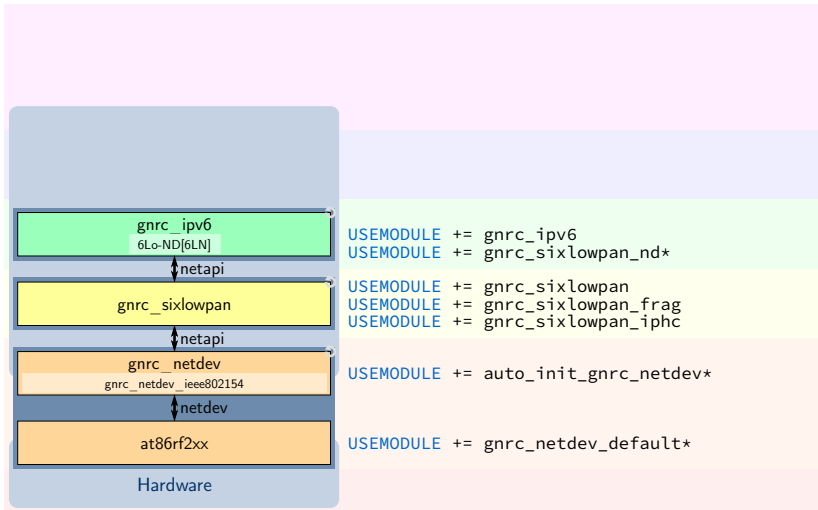
gnrc_minimal example (native)

- ▶ * = name might be subject to change



gnrc_minimal example (samr21-xpro)

- ▶ * name might be subject to change



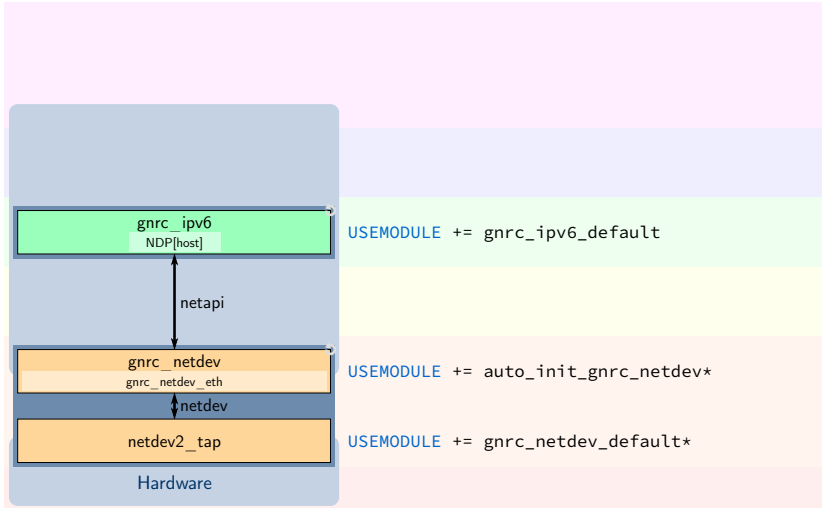
Some short-cuts (Makefile.dep)

Pseudo-module dependencies

- ▶ `gnrc_sixlowpan_default:`
 - ▶ `gnrc_sixlowpan`
 - ▶ `gnrc_sixlowpan_frag`
 - ▶ `gnrc_sixlowpan_iphc`
- ▶ `gnrc_ipv6_default:`
 - ▶ `gnrc_ipv6`
 - ▶ `gnrc_ndp_host` (if non-6Lo interface present)
 - ▶ `gnrc_sixlowpan_default` (if 6Lo interface present)
 - ▶ `gnrc_sixlowpan_nd` (if 6Lo interface present)

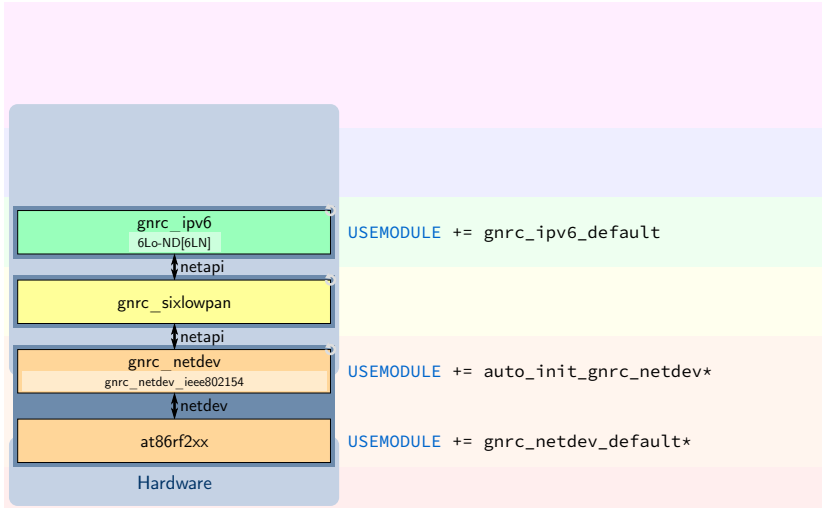
gnrc_minimal example (native)

- ▶ * = name might be subject to change



gnrc_minimal example (samr21-xpro)

- ▶ * = name might be subject to change



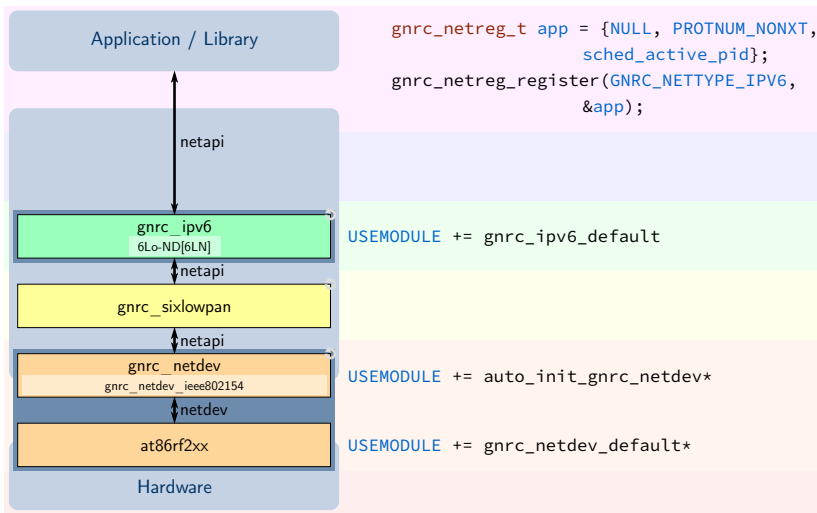
Task 7.1 – Compile the gnrc_minimal application

- ▶ Go to the gnrc_minimal application (`cd gnrc_minimal`)
- ▶ Compile and run on native
- ▶ Should print something like My address is
fe80::d403:24ff:fe89:2460
- ▶ Ping RIOT instance from Linux:

```
ping6 <RIOT-IPv6-addr>%tap0
```

gnrc_minimal example (samr21-xpro)

- ▶ Adding a simple application
- ▶ * = name might be subject to change



Task 7.2 – Extend gnrc_minimal application

- ▶ Add the gnrc_udp module to the application
- ▶ Register for UDP packets of port 8888

```
/* include "sched.h" and "net/gnrc/netreg.h"! */
unsigned int count = 0; msg_t msg;
gnrc_netreg_t server = {NULL, 8888, sched_active_pid};
gnrc_netreg_register(GNRC_NETTYPE_UDP, &app);

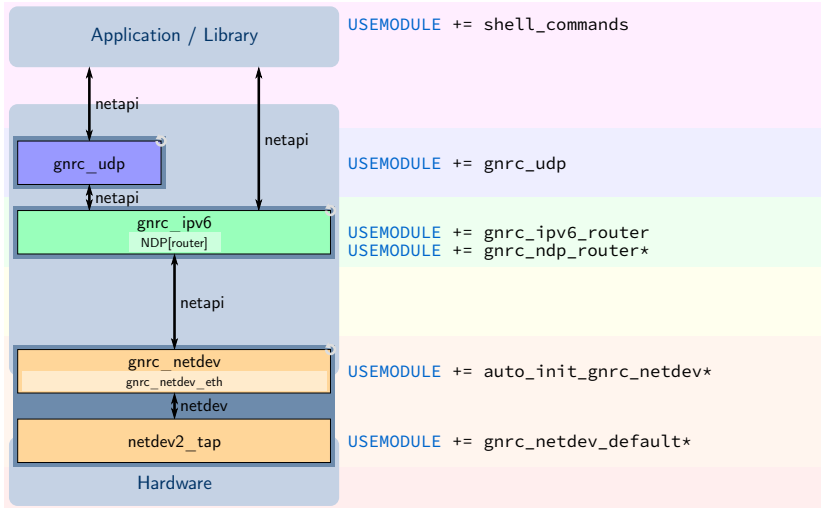
while (1) {
    msg_receive(&msg);
    printf("Received %u UDP packets\n", ++count);
}
```

- ▶ Compile and run on native
- ▶ Send UDP packet to RIOT node using netcat

```
echo "hello" | nc -6u <RIOT-IPv6-addr>%tap0 8888
```

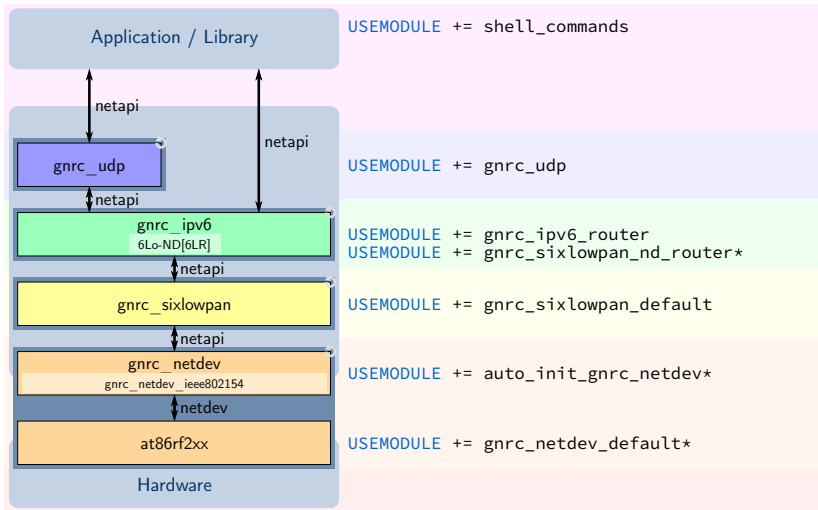
gnrc_networking example (native)

- ▶ * = name might be subject to change



gnrc_networking example (samr21-xpro)

- ▶ * = name might be subject to change



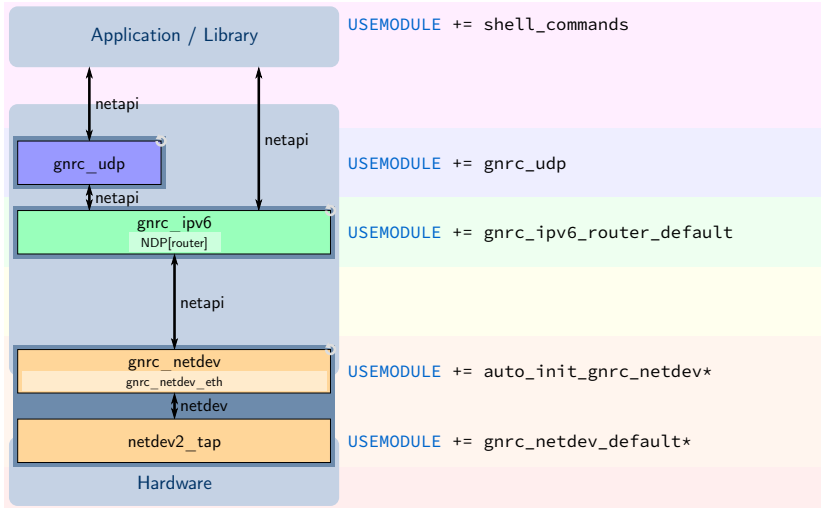
More short-cuts (Makefile.dep)

Pseudo-module dependencies

- ▶ `gnrc_ipv6_router_default`:
 - ▶ `gnrc_ipv6`
 - ▶ `gnrc_ndp_router` (if non-6Lo interface present)
 - ▶ `gnrc_sixlowpan_default` (if 6Lo interface present)
 - ▶ `gnrc_sixlowpan_nd_router` (if 6Lo interface present)

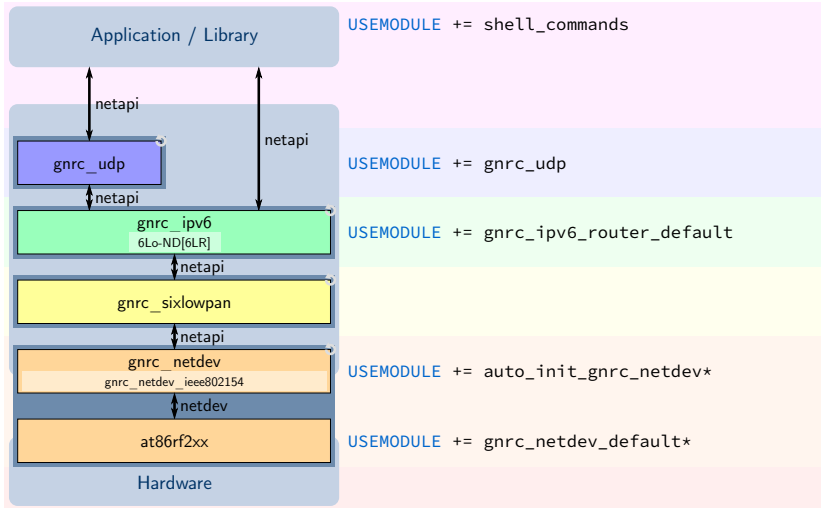
gnrc_networking example (native)

- * = name might be subject to change



gnrc_networking example (samr21-xpro)

- ▶ * = name might be subject to change

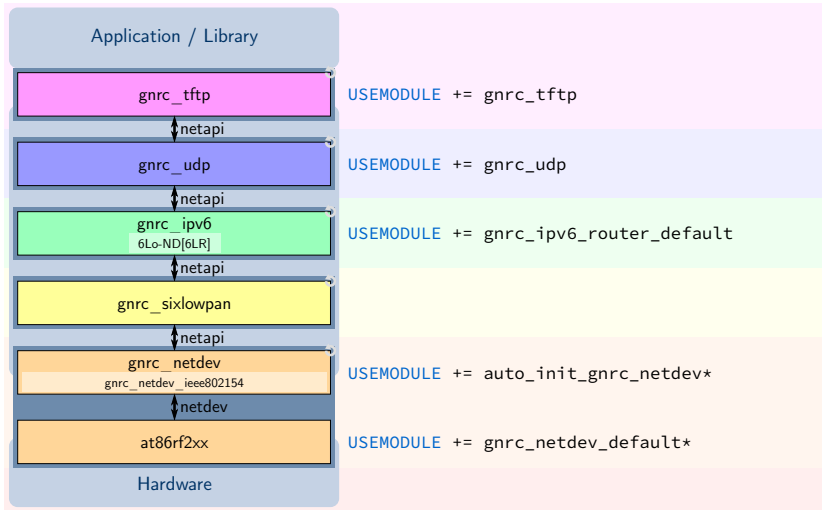


Task 7.3 – Send your neighbor some messages again

- ▶ Go to gnrc_networking example: `cd ../gnrc_networking`
- ▶ Have a look in `udp.c` how packets are constructed and send
- ▶ Compile, flash, and run on the board `BOARD=samr21-xpro`
`make all flash term`
- ▶ Type `help`
- ▶ Start UDP server on port 8888 using `udp server 8888`
- ▶ Get your IPv6 address using `ifconfig`
- ▶ Send your neighbor some messages using `udp send`

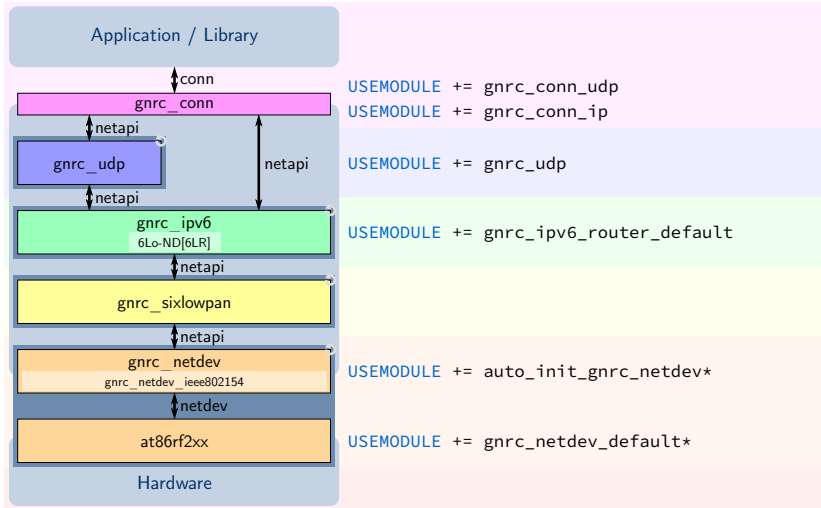
gnrc_tftp example

- ▶ for simplicity only the samr21-xpro examples from now on
- ▶ * = name might be subject to change



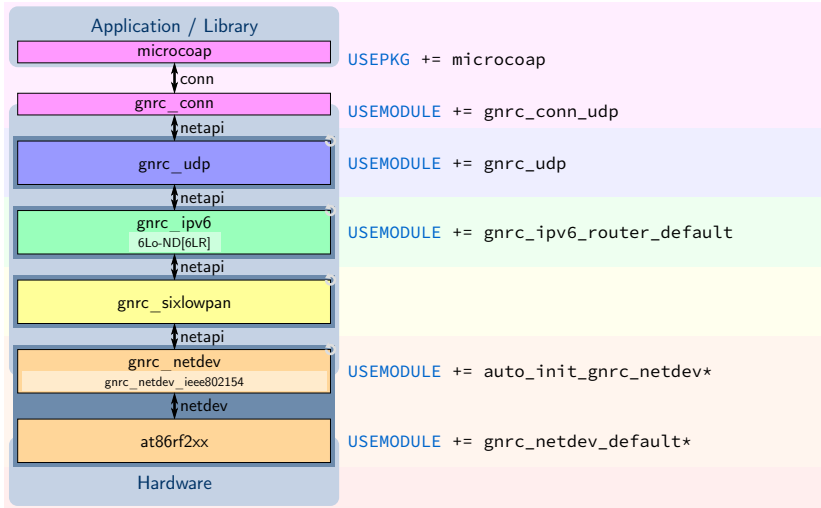
Make your application stack independent

- ▶ * = name might be subject to change



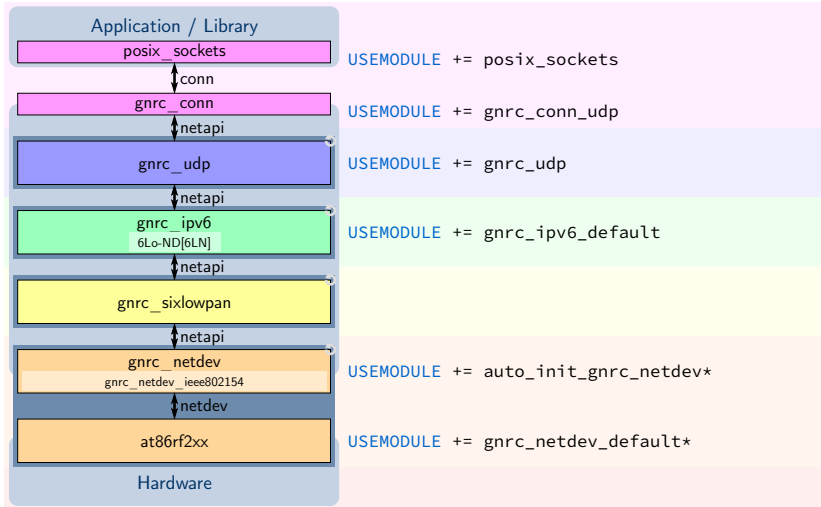
microcoap example

- ▶ * = name might be subject to change



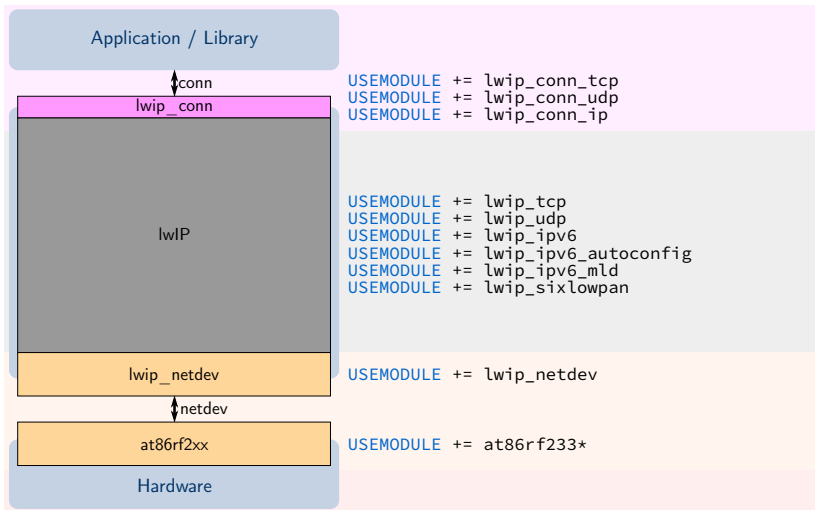
posix_sockets example

- ▶ * = name might be subject to change



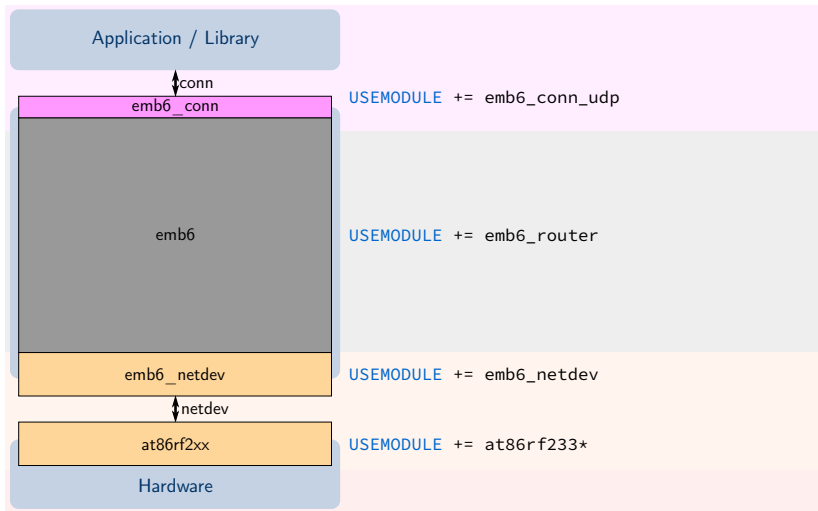
LwIP instead of GNRC

- ▶ * = name might differ on other devices



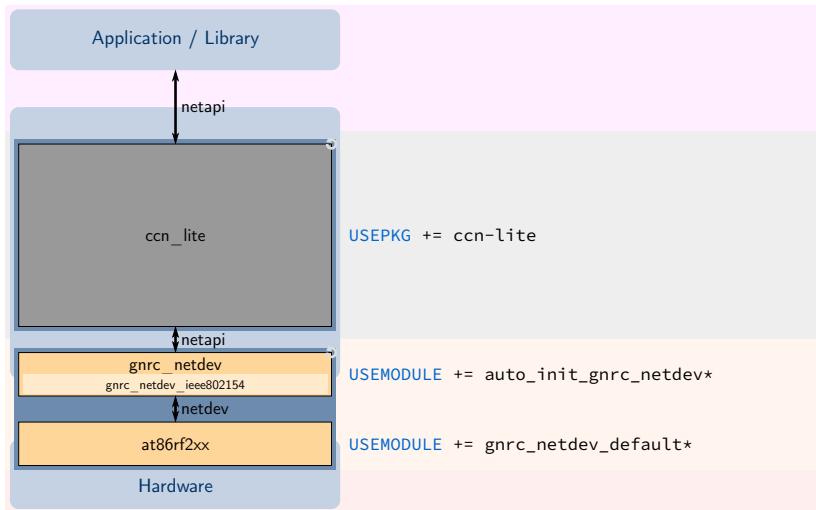
emb6 (uIP-fork) instead of GNRC

- ▶ * = name might differ on other devices



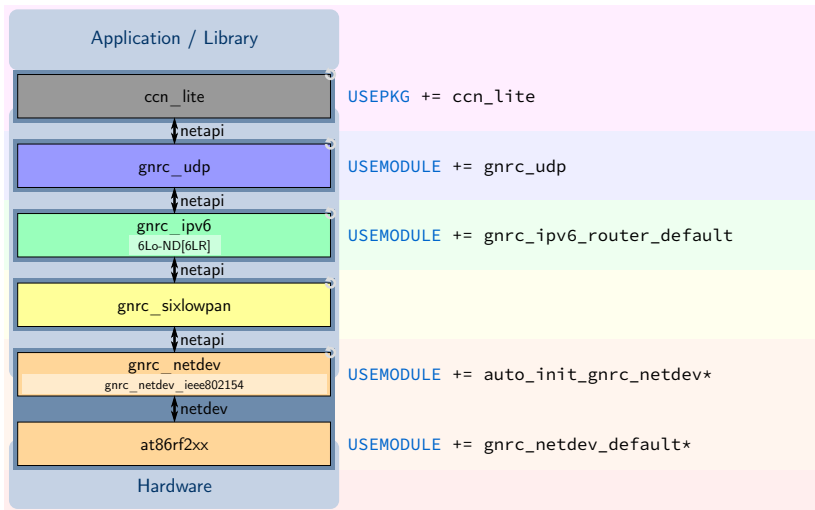
ccn_lite_relay example

- ▶ * = name might be subject to change



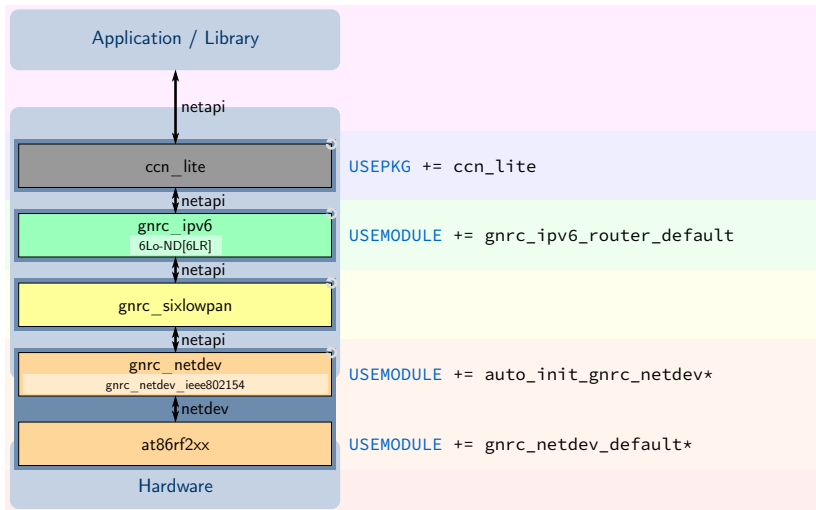
CCN-lite over UDP example

- ▶ * = name might be subject to change



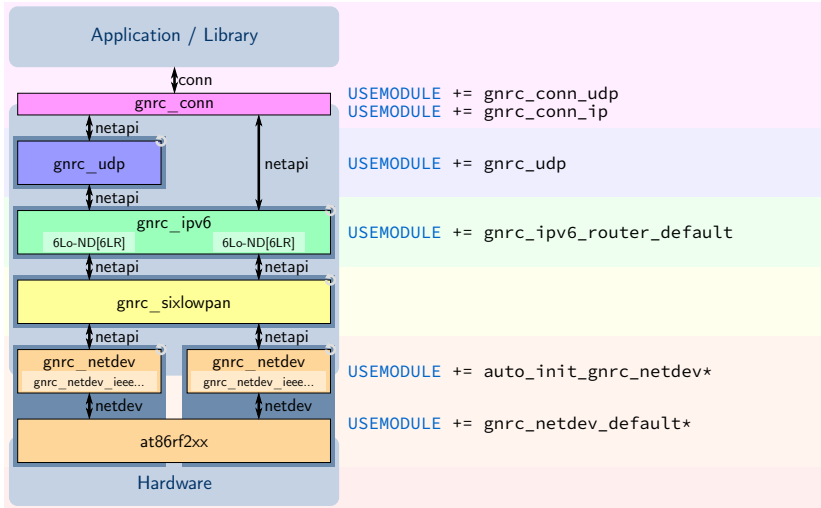
CCN-lite over IPv6 example

- ▶ * = name might be subject to change



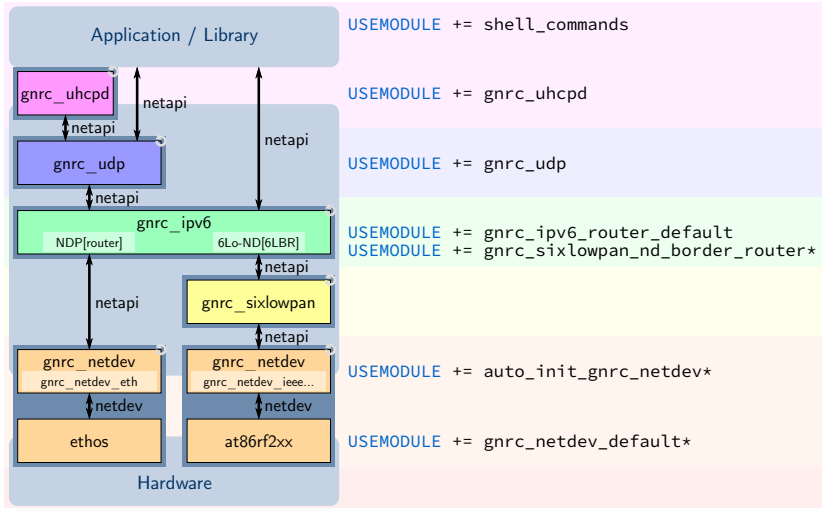
Example: multiple radios of the same type

- * = name might be subject to change



gnrc_border_router example

- ▶ * = name might be subject to change



Now go out and make something!