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A Journey through Unikraft's Build System

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5GCity

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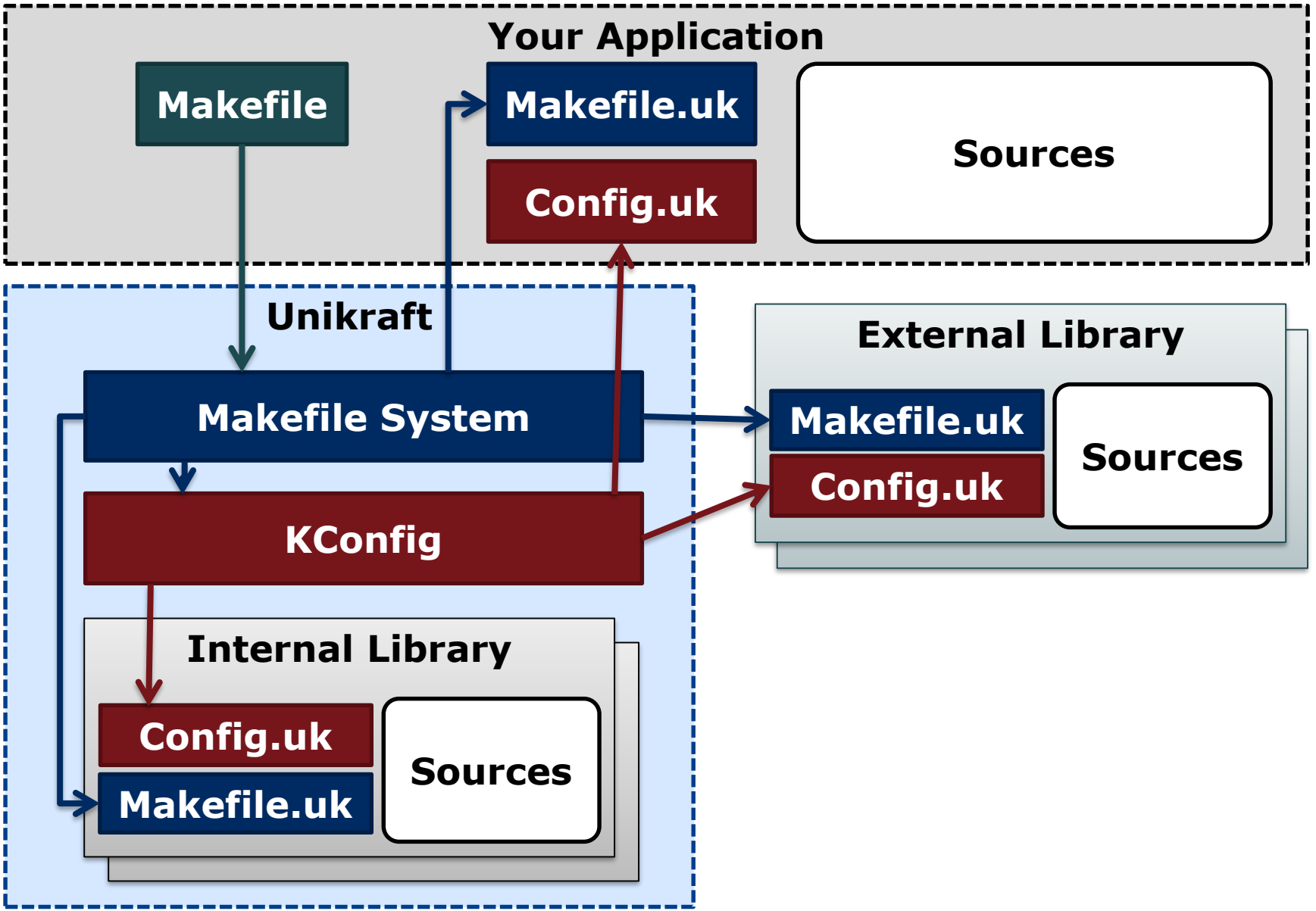
Unikraft's Build System

Overview

Build System: Loading & Parsing



Unikraft's 3 Build Stages

(1) Fetch

- Download and decompress external sources
  e.g., a library hosted on GitHub, Sourceforge
- Patch downloaded files

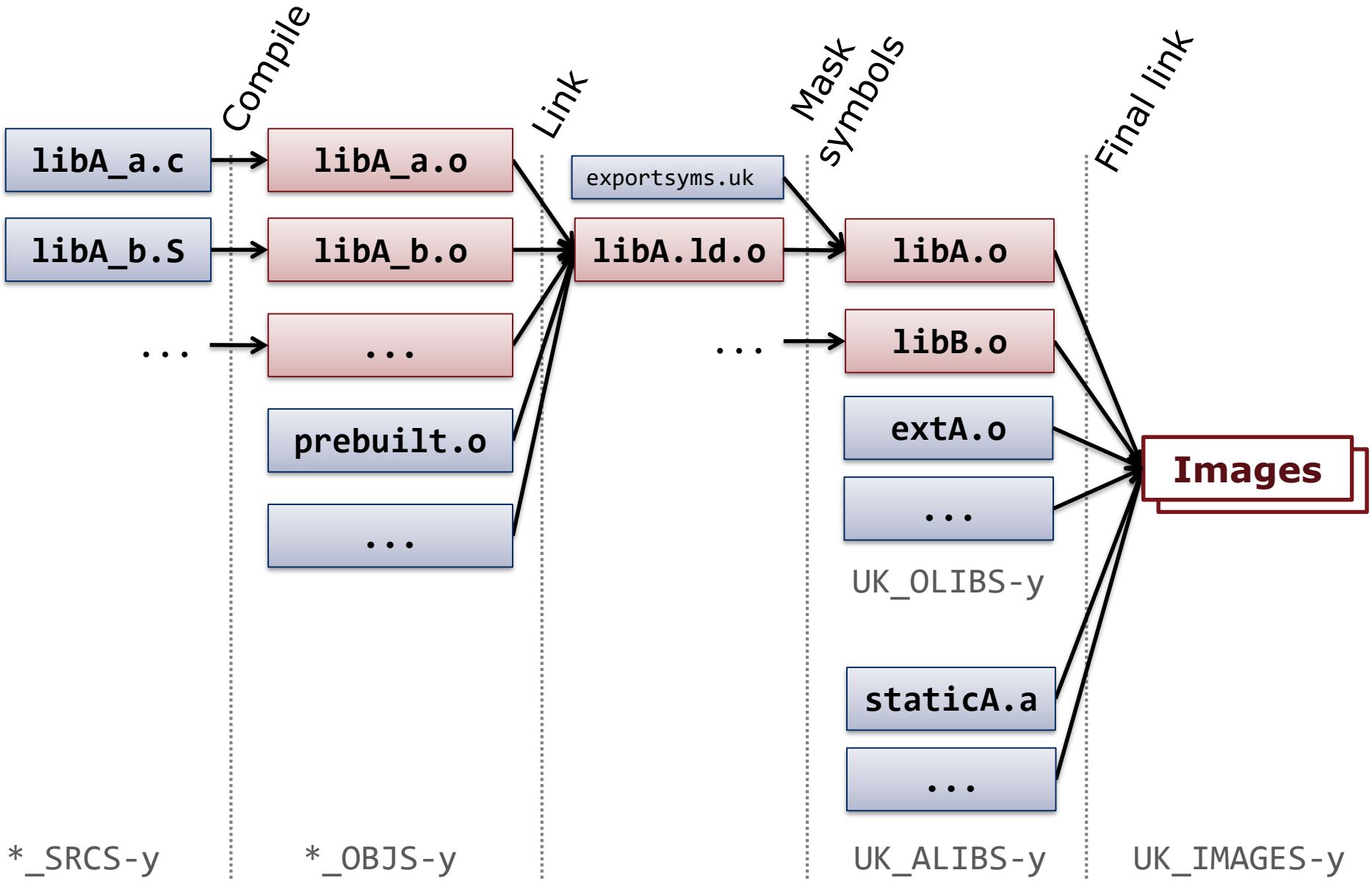
(2) Prepare

- Further preparation steps to the sources, for instance:
  - Call `./configure` of downloaded library sources
  - Generate further sources or headers required for building

(3) Compile & Link

- Compile sources
- Link libraries
- Link final images

Build Stage 3: Compiling and Linking



Make parameters

Unikraft's base Makefile

```
$ make A=[APP] L=[LIBRARIES] P=[PLATFORMS] V=[1/0] [target]
```

Parameter	Description
`A=[APP]`	Path to application directory
`L=[LIBRARIES]`	Colon-separated list of paths to external libraries
`P=[PLATFORMS]`	Colon-separated list of paths to external platform libs
`V=[1/0]`	Verbose mode (on/off)
`[target]`	**Build target**
`help`	Show overview of targets
`menuconfig`	Configure and select target images (default when there is no `.config`)
`all/images`	Build everything (default) *`+libs`*
`libs`	Build libraries *`+prepare`*
`prepare`	Run preparations steps *`+fetch`*
`fetch`	Download, extract, and patch external code

Unikraft Libraries

Integrate *own* libraries and applications

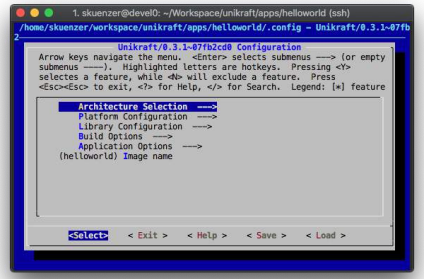
Libraries/Applications/Platforms: Necessary files

`Makefile` **applications only*

- Invoke Unikraft build for simplification

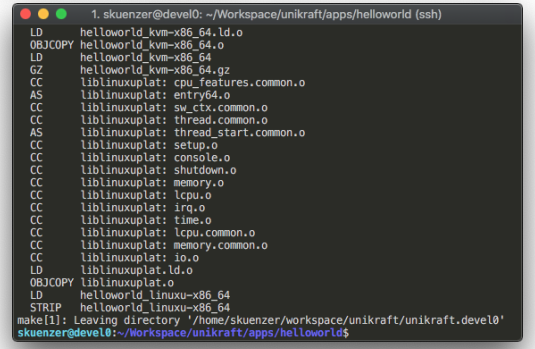
`Config.uk`

- Configuration options
  - Settings saved as part of `.config`
- Specifying library dependencies and depending options



`Makefile.uk`

- Registration to the build system
- Specification of source files
- Extra custom Make rules
  - For instance for preparing the sources



`exportsyms.uk`

- Masking of symbols

`Linker.uk` **platform libraries only*

- Platform-dependent rules for linking final image

Makefile **applications only*

- Simplify application building
- Changes to Unikraft base directory and invokes make

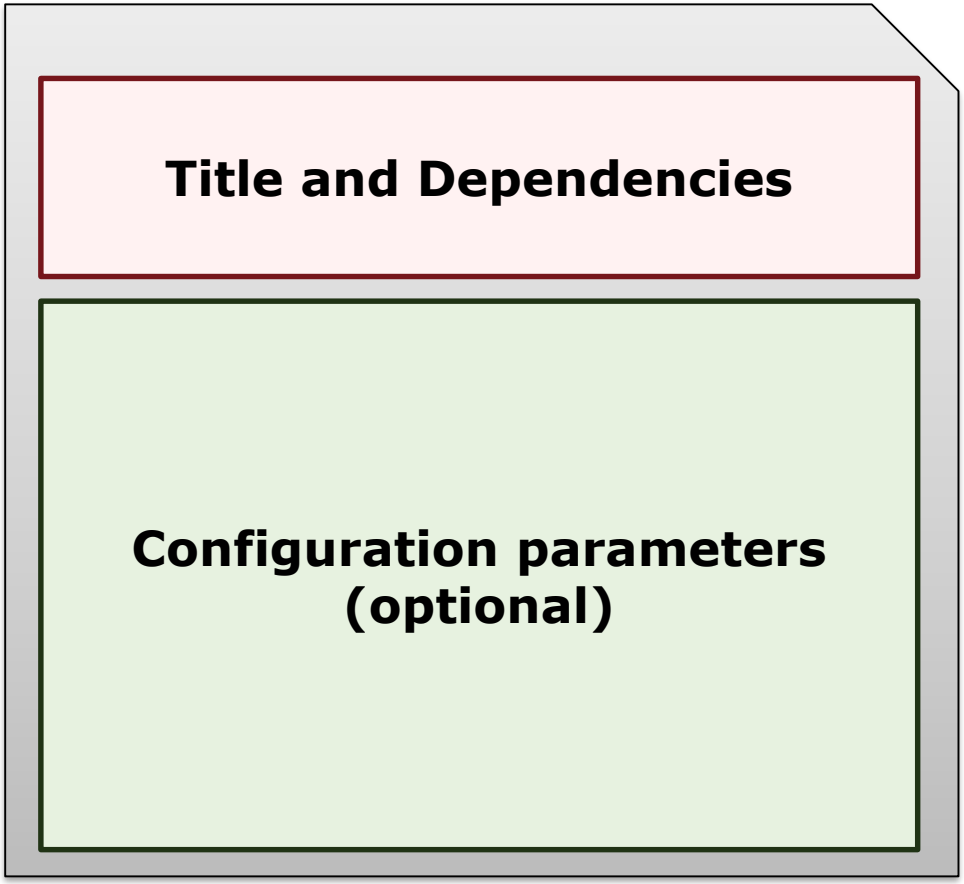
```
UK_ROOT   ?= $(PWD)/../../unikraft
UK_LIBS   ?= $(PWD)/../../libs
LIBS      := $(UK_LIBS)/libA:$(UK_LIBS)/libB

all:
	@$(MAKE) -C $(UK_ROOT) A=$(PWD) L=$(LIBS)

$(MAKECMDGOALS):
	@$(MAKE) -C $(UK_ROOT) A=$(PWD) L=$(LIBS) (MAKECMDGOALS)
```

Config.uk

- KConfig syntax[1]
- Structure:



[1] https://www.kernel.org/doc/Documentation/kbuild/kconfig-language.txt

Config.uk: Title and Dependencies for Libraries

```
menuconfig LIBMYLIB
        bool "ukmylib: my scheduler“
        ### libraries are off as default
        default n
        ### dependencies
        select LIBNOLIBC if !HAVE_LIBC

if LIBMYLIB
        ### list of configuration parameters goes here
endif
```

- `menuconfig` defines a submenu for the following configuration options
  - *Note: Use just* `config` *without following* `if`*-block when the library does not have any configuration parameters*
- `select` keyword is used to describe dependencies to other libraries
  - Supports conditional expressions[1]
  - Multiple `select` lines are possible for a single configuration

Config.uk: Dependencies for Applications

```
### Invisible option (no description) that is set as
### default to ‚y‘ in order to select dependencies
config LIBMYAPP
        bool
        default y
        select LIBNOLIBC if !HAVE_LIBC

### list of configuration parameters goes here
```

- Invisible `bool config` to select dependencies
  - Applications are not defining an own submenu. Because just a single application can currently be selected for one Unikernel build, applications are enabled as default
- Like for libraries, `select` keyword is used to describe dependencies to libraries

Config.uk: Configuration Parameter

```
config LIBMYLIB_SETTING
        [type] "[description]"
        default [value]
        select LIBOTHER
```

- Name-space configuration options!
  - Prepend library name in front of parameters: *here:* `LIBMYLIB_`
- Configurations will appear as `CONFIG_[CONFIGNAME]` in the build system and in the sources (include `uk/config.h`) (*here:* `CONFIG_LIBMYLIB_SETTING`)
- `[type]` can be one of bool, int (unsigned), hex, string:

	Makefile.uk	#include <uk/config.h>
bool	y/n	„y" is defined as 1 „n" is not defined
int	Hexadecimal	Defined as hexadecimal
hex	Hexadecimal	Defined as hexadecimal
string	String	Defined as String

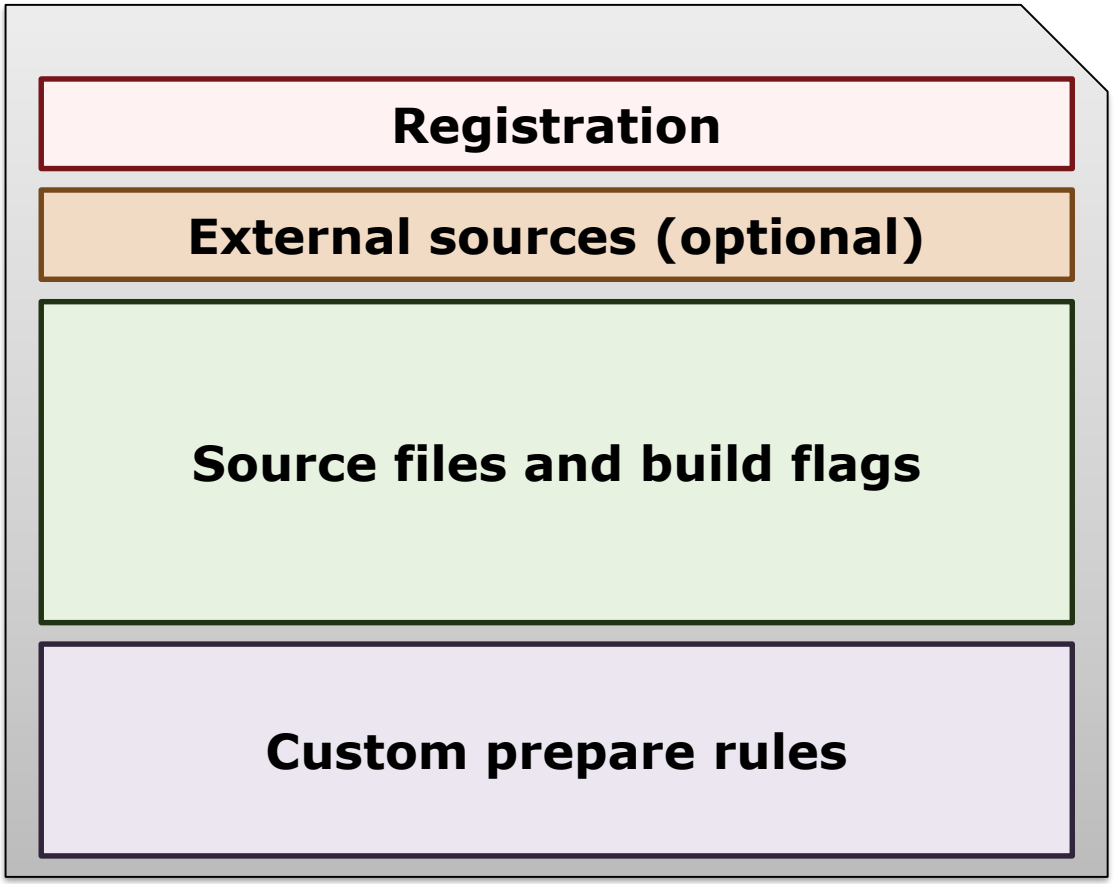
- Advanced options, like choice lists, are documented at: https://www.kernel.org/doc/Documentation/kbuild/kconfig-language.txt

Makefile.uk

Makefile syntax

- Unikraft provides helper functions and variables
- Unikraft expects specific variables to be filled

Structure



Makefile.uk: Registration

Registration with `addlib` / `addlib_s` helpers[1]

- The first thing that has to be done in a `Makefile.uk`
- Libraries (depending on being enabled)
  Replace `[libmylib]` and `CONFIG_LIBMYLIB` accordingly:

```
$(eval $(call addlib_s,[libmylib],$(CONFIG_LIBMYLIB)))
```

- Applications
  Replace `[libmyapp]` accordingly:

```
$(eval $(call addlib,[libmyapp]))
```

- The namespace for variables is defined by application/library name
  here: prefixed in uppercase: `LIBMYLIB_`, `LIBMYAPP_`
- The following variables are populated after the call

`*_BASE`	Path to library folder
`*_BUILD`	Path to library's output/build folder *Note: Place all generated files during building in here, never in the base*

- The following overrides are available after the call

`*_EXPORTS`	Path to an alternative `exportsyms.uk` (optional)

[1] `support/build/Makefile.rules`

Makefile.uk: External sources (optional)

- Download one archive with (additional) sources and extract them with `fetch` / `fetchas` helpers[1]
  - Example with lwIP:

```
LIBLWIP_ZIPNAME=lwip-2.1.2
LIBLWIP_URL=http://download.savannah.nongnu.org/releases/lwip/$(LIBLWIP_ZIPNAME).zip
$(eval $(call fetch,liblwip,$(LIBLWIP_URL)))
```

  - `.tar.gz`, `.tgz`, `.tar.xz`, `.txz`, and `.zip` are currently supported[1]
  - The following variables are populated after this call

`*_ORIGIN`	Path to folder containing extracted archive files

- If some downloaded source files need to be patched, use `patch` helper[1]:
  - Example with lwIP:

```
LIBLWIP_PATCHDIR=$(LIBLWIP_BASE)/patches
$(eval $(call patch,liblwip,$(LIBLWIP_PATCHDIR),$(LIBLWIP_ZIPNAME)))
```

  - This command applies all patches found in `$(LIBLWIP_PATCHDIR)` to the sub-directory `$(LIBLWIP_ZIPNAME)` of the previously extracted sources

[1] `support/build/Makefile.rules`

Makefile.uk: Source files

Full paths to source files are added to the *_SRCS-y list:

```
# Source file from library directory
LIBMYLIB_SRCS-y += $(LIBMYLIB_BASE)/source.c

# Source file from extracted archive
LIBMYLIB_SRCS-y += $(LIBMYLIB_ORIGIN)/another_src.c
```

- Compile rule and target is automatically generated by build system based on file extension:
  - Currently supported: `.S`, `.sx`, `.s`, `.c`, `.C`, `.cc`, `.cp`, `.cxx`, `.cpp`, `.CPP`, `.c++`, `.lds.S`
  - .o-binary is created within the library output directory based on the source filename:

```
$(LIBMYLIB_BASE)/source.c.       → $(LIBMYLIB_BUILD)/source.o
$(LIBMYLIB_ORIGIN)/another_src.c → $(LIBMYLIB_BUILD)/another_src.o
```

    - Note: Only the filename without extension matters for the target file name. The source file extension and path is irrelevant. In conflicting cases, use variants (see next slide).
- The following include and build flag lists apply for a source file:

`CFLAGS-y`	Global build flags (*here*: C sources, equivalents for other types exist)
`CINCLUDES-y`	Global includes (*here*: C sources, equivalents for other types exist)
`*_CFLAGS-y`	Library-internal build flags (*here*: C sources, equivalents exist)
`*_CINCLUDES-y`	Library-internal includes (*here*: C sources, equivalents exist)
`*_[FILENAME]_FLAGS`	Source file specific build flags
`*_[FILENAME]_INCLUDES`	Source file specific includes

Makefile.uk: Source File Variants

Variants exist because of two reasons:

- Conflicting output file names (previous slide)
- Necessity to compile a single source file multiple times with different flags (e.g., newlib *scanf() variants)

Variant names are added with a pipe symbol after source:

```
LIBMYLIB_SRCS-y += $(LIBMYLIB_BASE)/source.c
LIBMYLIB_SRCS-y += $(LIBMYLIB_BASE)/source.c|variant
LIBMYLIB_SRCS-y += $(LIBMYLIB_ORIGIN)/source.c|origin
```

- …produces:

```
$(LIBMYLIB_BASE)/source.c          → $(LIBMYLIB_BUILD)/source.o
$(LIBMYLIB_BASE)/source.c|variant  → $(LIBMYLIB_BUILD)/source.variant.o
$(LIBMYLIB_ORIGIN)/source.c|origin → $(LIBMYLIB_BUILD)/source.origin.o
```

- Variants have their own specific build flags and includes:

*_[FILENAME]_FLAGS	Build flags for source file without variant specification
*_[FILENAME]_INCLUDES	Includes for source file without variant specification
*_[FILENAME]_[VARIANT]_FLAGS	Build flags for source file for variant [VARIANT]
*_[FILENAME]_[VARIANT]_INCLUDES	Includes for source file for variant [VARIANT]

Makefile.uk: Externally Compiled Sources

- Unikraft supports including externally compiled sources
  Cases where it may happen:
  - Code only available as binary form
  - Compiling is done by different build system
    (e.g., invoked by custom prepare rules)

- Depending on the type, various places exist to add them:
  - `.o`-object files are added to the `*_OBJS-y` list:

```
LIBMYLIB_OBJS-y += $(LIBMYLIB_BASE)/prebuilt.o
```

  - `.o`-libraries are registered to the global list `UK_OLIBS`
    (remember to use the library switch `CONFIG_*`):

```
UK_OLIBS-$(CONFIG_LIBMYLIB) += $(LIBMYLIB_BASE)/prebuilt_lib.o
```

  - Static libraries are registered to the global list `UK_ALIBS`
    (remember to use the library switch `CONFIG_*`):

```
UK_ALIBS-$(CONIG_LIBMYLIB) += $(LIBMYLIB_BASE)/static_lib.a
```

  - *Note: Shared libraries (`.so`) are currently not supported*

Makefile.uk: Scope of Headers (Includes)

- Global headers (e.g., library API)
  (remember to use the library switch `CONFIG_*`):

```
CINCLUDES-$(CONFIG_LIBMYLIB) += -I$(LIBMYLIB_BASE)/include/api
```

- Library-Internal headers

```
LIBMYLIB_CINCLUDES-y += -I$(LIBMYLIB_BASE)/include/internal
```

- File-specific headers

```
# mysrc.c
LIBMYLIB_MYSRC_INCLUDES      += -I$(LIBMYLIB_BASE)/include/mysrc

# Variant var0 of mysrc.c: mysrc.c|var0
LIBMYLIB_MYSRC_VAR0_INCLUDES += -I$(LIBMYLIB_BASE)/include/mysrc
```

- Equivalent to this, you can set build flags within a specific scope
  - `CFLAGS-$(CONFIG_LIBMYLIB), LIBMYLIB_CFLAGS-y, LIBMYLIB_MYSRC_FLAGS, LIBMYLIB_MYSRC_VARIANT_FLAGS`

Makefile.uk: Custom Prepare Rules

Reason

- Generate files (headers, sources) needed for build
- Invoke parts of ported library build system, like `./configure`

Defined as custom Make rules

- Use `build_cmd` to prettify the output[1]
  (in cases where `build_cmd` is not applicable use `verbose_cmd`)

```
$(LIBMYLIB_BUILD)/generated.h: [dependencies]
   $(call build_cmd,NM,libmylib,$@,$(NM) -n $(LIBMYLIB_BASE)/symtab.in > $@)
```

If used, set marker of fetch stage as dependency

- Download marker: `$(LIBMYLIB_BUILD)/.origin`
- Patched marker: `$(LIBMYLIB_BUILD)/.patched`

Register generated files to prepare stage

```
UK_PREPARE-$(CONFIG_LIBMYLIB) += [generated file/phony]
```

[1] `support/build/Makefile.rules`

exportsyms.uk

- Re-masks the scope of each symbol of a library
  - Re-defines for each symbol if it is available for final linking
  - Intended to reduce potential clashing of symbols

- List of symbol names that should be available globally for final linking. Non-listed symbols become private to the library.
  - *Example (libnolibc):*

```
asprintf
vasprintf

# comments are ignored
opterr
optind
optopt
optreset
optarg
getopt
[...]
```

- Note: The build system will throw a warning when no `exportsyms.uk` file is provided
  - The scope of each library symbol stays unchanged in such a case

Best Practices

Best Practices

Porting existing libraries/applications is a challenging task

- Existing sources often only fit to their build and configuration system
- Often not intended to run on something else than Linux (assumptions to the OS)

If possible, compile all sources with Unikraft

- Including external build binaries is risky
  - Build flags may be incompatible (e.g., register usage/calling convention, LTO)
  - Mismatch of depending libraries (external vs. Unikraft's version)

Learn from existing build system

- Extract list of source files and build flags when compiling with original build system
- Study steps that generate files needed for the build
  - Try to run `./configure` with settings fitting to Unikraft environment
  - It is also possible to call `./configure` from Unikraft as prepare step

Provide initial stubs for missing symbols

- Completing compiling & linking (but not running) first,
  helps to get an better overview of missing functionality in Unikraft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