Towards Rapid Development of Component Tools at LLNL

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Leveraging existing research work at LLNL is done frequently,

- **Ph.D. students typically work on small research tool projects**
  - Need specific functionality very quickly
  - With more Ph.D. students, assisting all of them with the development work becomes less feasible.

- **Typical performance tool requires a lot of extra coding**
  - Measurement infrastructure
    - PMPI, profilers, hardware counters, timers
  - Tracking layers (MPI Requests, Datatypes, etc)
  - Actual research work is a very small part

- **Building all these tools can be the most time consuming part**
  - Research tools aren't extensively tested, tools are buggy
    - Many spend time debugging others' tools
  - Often made to work for one machine, one set of benchmarks, one app
  - Not many students know how to write a good build system

We are adopting three frameworks to enable more rapid

1. **Using P^{N}MPI for tool integration**
   - Enables us to reuse PMPI measurement modules
   - Allows modules to talk to each other
   - Can rapidly build/test PMPI modules without writing custom shim layer

PnMPI

2. **Modular build system**
   - Using CMake for tool builds
   - Pain of finding, linking, patching PnMPI modules is greatly reduced.

CMake

3. **Wrapper generator for PMPI libraries**
   - Extended existing MPE wrapper generator
   - Added lists, expression language
   - Working on more semantic information in the API

wrap.py

Quick Tool Prototyping with P^{N}MPI

- **PMPI interception of MPI calls**
  - Used by many MPI tools
  - Limited to a single tool

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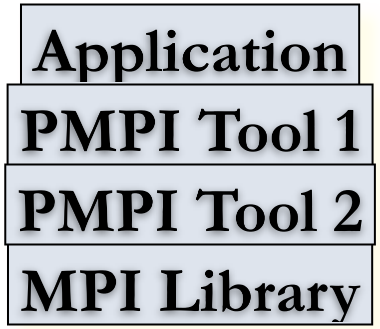
- **P^{N}MPI virtualized PMPI**
  - Multiple tools concurrently
  - Dynamic loading of tools
  - Configuration through text file
  - Tools are independent
  - Tools can collaborate



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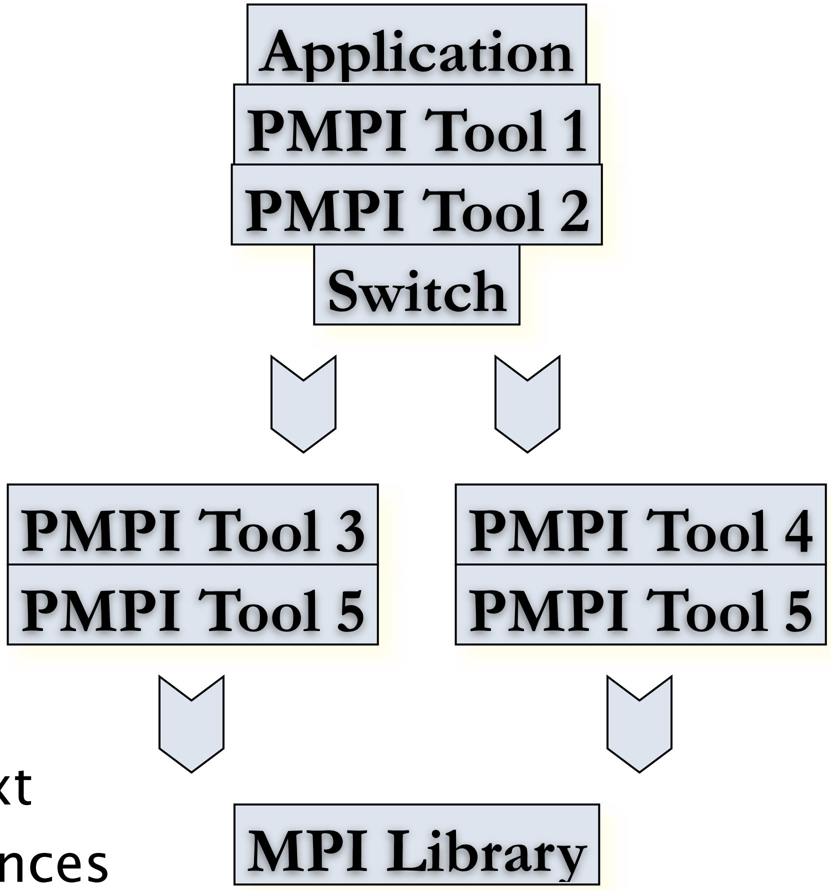
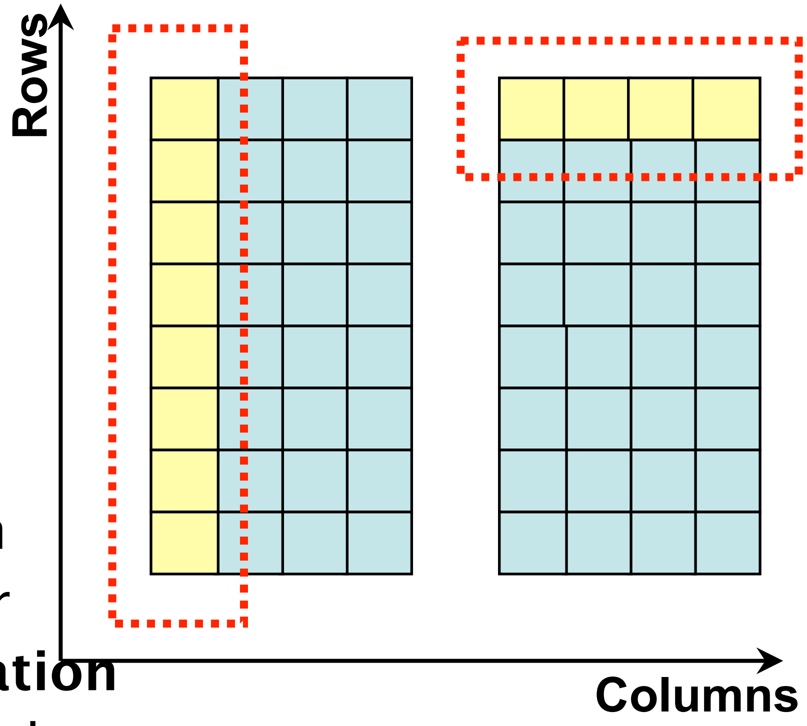
- **Transparently adding context**
  - Select tool based on MPI context
  - Transparently isolate tool instances


Application
PMPI Tool 1
PMPI Tool 2
Switch
PMPI Tool 3
PMPI Tool 5
PMPI Tool 4
PMPI Tool 5
MPI Library

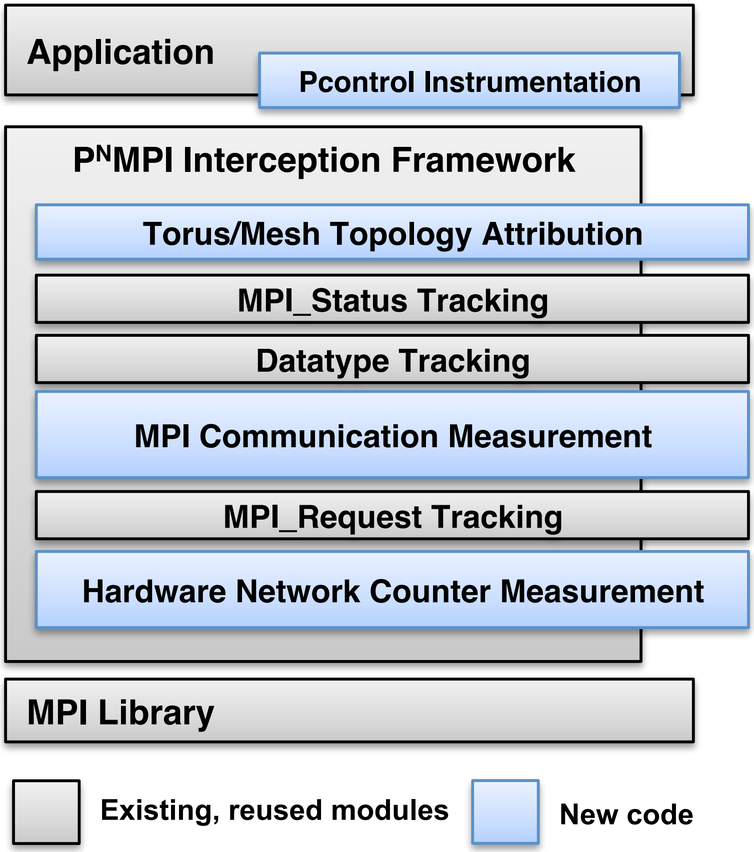
Example: Optimizing an FPMD Code



- **Data structure: dense matrix**
  - Row and column communicators
  - Additional global operations
  - Standard profiles aggregate data
- **Need to profile separately**
  - Potentially different operations
  - May lead to separate optimization
  - BUT: don't want to rewrite profiler
- **Switch module to split communication**
  - Create three independent tool stacks
  - Apply unmodified profiler (mpiP) in each stack
  - Transparent to profiler, application & MPI library

P^{N}MPI allows PAVE tools to be factored into modules and run concurrently

- **We are able to leverage existing communication measurement for P^{N}MPI**
  - BG/P network counter module
  - Request, datatype tracking modules
- **Allows application-specific analysis with minimal additional work**
  - Using existing modules is as simple as adding lines to a configuration file
  - Don't need to modify PMPI code
- **Building and integrating new modules can be painful**



Application

Pcontrol Instrumentation

P^{N}MPI Interception Framework

Torus/Mesh Topology Attribution

MPI_Status Tracking

Datatype Tracking

MPI Communication Measurement

MPI_Request Tracking

Hardware Network Counter Measurement

MPI Library

⬜ **Existing, reused modules** 🟦 **New code**

We use CMake to streamline our build process

- **Finding packages and modules on large systems is difficult**
  - Aren't detected easily by other tools if not part of the system
  - Writing portable, custom m4 for autotools can be painful
  - Keeping versions, LD_LIBRARY_PATHs straight is painful

- **Finding external packages built with CMake is easier**
  - CMake allows projects to export key build information
  - Modules simply tell other modules where to find libraries and headers, rather than requiring the user to do this
  - Exporting this information in CMake is very easy

- **Integrates well with dot kits on LLNL machines**
  - Should also integrate with modules (untested)

Building P^{N}MPI Modules with Make vs. CMake

- **Makefile shown at right:**
  - Requires 4 environment variables to be set by user
  - User must know how to write rules to patch PnMPI modules manually
  - User needs platform-specific knowledge of linking shared libraries
  - User manually writes wrapper generator rules
- **None of this is difficult if you are experienced with builds**
  - **BUT**, it can be very tedious
  - Requires build/link/tool-specific knowledge

```
include $(PNMPIBASE)/common/Makefile.common

MOD     = virtual.so
MPISPEC = mpi_pnmpi
#MPISPEC = mpi_def
WRAPDIR = ../../wrapper
PROTOFILE = $(WRAPDIR)/$(MPISPEC)_proto
FCTFILE   = $(WRAPDIR)/$(MPISPEC)_fct
WRAPPERC = wrapper_c.w
WRAPPERH = wrapper_h.w
WR = ../../wrappergen/wrappergen
CFLAGS += -I$(PNMPI_INC_PATH) -fPIC
CCFLAGS += -I$(PNMPI_INC_PATH) -fPIC

all: $(MOD) install
virtual.so: virtual.o
$(CROSSLD) -o $@ $(SFLAGS) $<
virtual.o: virtual.c virtual.h
$(MPICC) -c $(CFLAGS) $<
virtual.h: virtual.w
$(WR) -p $(PROTOFILE) -f $(FCTFILE) -w $< -o $@
install: $(MOD)
for mymod in $(MOD); do \
(../../patch/patch $$mymod $(PNMPI_LIB_PATH)/$$mymod );
done
clean:
rm -f $(MOD) *.o virtual.h
clobber: clean
rm -f *~
```

Building P^{N}MPI Modules with Make vs. CMake

```
find_package(PnMPI REQUIRED)
Find_package(MPI REQUIRED)

add_pnmpi_module(virtual virtual.c)
add_wrapped_file(virtual.c virtual.w)

install(TARGETS virtual DESTINATION ${PnMPI_MODULES_DIR})

include_directories(
${PnMPI_INCLUDE_PATH}
${MPI_C_INCLUDE_PATH})
```

- **Equivalent CMake file:**
  - No environment variables needed
  - P^{N}MPI is automatically located by the build
    - — P^{N}MPI exports build information, build can simply import this
- **Build uses variables and functions supplied by P^{N}MPI**
  - `add_pnmpi_module()`
  - `add_wrapped_file()`
  - `${PNMPI_MODULES_DIR}` is the install location

Building P^{N}MPI Modules with Make vs. CMake

```
find_package(PnMPI REQUIRED)
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add_pnmpi_modu
add_wrapped_fil

install(TARGETS virtual D

includ
${PnMP
${MPI_
```

This code is provided by PnM

```
function(add_pnmpi_module targetname)
   # Add a library for the module
  add_library(${targetname} MODULE ${ARGN})

  # Patch the library in place once it's built
get_target_property(lib   ${targetname} LOCATION)
get_target_property(patch pnmpi-patch   LOCATION)
   set(tmplib ${targetname}-unpatched.so)

add_custom_command(TARGET ${targetname} POST_BUILD
     COMMAND mv       ARGS ${lib} ${tmplib}
     COMMAND ${patch} ARGS ${tmplib} ${lib}
       COMMAND rm        ARGS -f ${tmplib}
   WORKING_DIRECTORY ${CMAKE_CURRENT_BINARY_DIR}
        COMMENT "Patching ${targetname}"
               VERBATIM)

  # Make sure that PnMPI lib and patch tool
     # are built before this module.
add_dependencies(${targetname} pnmpi-patch pnmpi)
          endfunction()
```

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- Build uses variables and functions supplied by P^{N}MPI
  - `add_pnmpi_module()`
  - `add_wrapped_file()`
  - `${PNMPI_MODULES_DIR}` is the install location

Exporting build information in CMake projects is simple

Code doing the exporting:

```
add_library(MyModule module.c wrapper.c)
add_wrapped_file(wrapper.c wrapper.w)
install(TARGETS MyModule EXPORT MyModule-libs DESTINATION lib)
install(EXPORT MyModule-libs DESTINATION share/cmake/MyModule)

install(FILES MyModule-config.cmake DESTINATION share/cmake/MyModule)
```

Client project attempting to find above library:

```
find_package(MyModule REQUIRED)
add_executable(myexe myexe.c)
target_link_libraries(myexe MyModule)
```

- **Each project exports a file that supplies build information (library, include locations, etc.)**
  - Other projects can use MyModule’s libraries easily
  - Client projects simply import information from MyProject
    - MyProject location is supplied in environment or at build time
    - Environment variables are easy to set in dotkits or environment modules
- **Makes integration of our own tools simple**
  - No custom m4 scripts needed for CMake projects

Exporting build information in CMake projects is simple

Code doing the exporting:

```
add_library(MyModule module.c wrapper.c)
add_wrapped_file(wrapper.c wrapper.w)
install(TARGETS MyModule EXPORT MyModule-libs DESTINATION lib)
install(EXPORT MyModule-libs DESTINATION share/cmake/MyModule)

install(FILES MyModuleConfig.cmake DESTINATION share/cmake/MyModule)
```

Client project attemp

```
# Various important directories in the PnMPI installation.
set(MyModule_INSTALL_PREFIX          @CMAKE_INSTALL_PREFIX@)
set(MyModule_INCLUDE_DIR             @CMAKE_INSTALL_PREFIX@/include)
set(MyModule_LIBRARY_DIR             @CMAKE_INSTALL_PREFIX@/lib)
set(MyModule_CMAKE_INCLUDE_DIR       @CMAKE_INSTALL_PREFIX@/share/cmake/MyModule)

include(${MyModule_CMAKE_INCLUDE_DIR}/MyModule-libs.cmake)
```

- **Each project ex locations, etc.)**
  - Other projects can use MyModule's libraries easily
  - Client projects simply import information from MyProject
    - MyProject location is supplied in environment or at build time
    - Environment variables are easy to set in dotkits or environment modules
- **Makes integration of our own tools simple**
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Cmake has more robust compile/link options

- Knows about GNU, Intel, XL, Pathscale, PGI, Visual Compilers
- Full support for rpath
  - Used extensively at LLNL due to number/versions of installed packages
- Platform/compiler/language-specific flags for:
  CMAKE_SHARED_LIBRARY_${lang}_FLAGS
  CMAKE_SHARED_LIBRARY_CREATE_${lang}_FLAGS
  CMAKE_SHARED_LIBRARY_RUNTIME_${lang}_FLAG

- Full control over link line for exe's and libs via
  - CMAKE_${lang}_LINK_EXECUTABLE
  - Useful for special XL/GNU flags used for dynamic executables on BG/P

- Platform support files are relatively easy to write
  - We did BlueGene/P support for static and dynamic libs
    - boost-cmake build for BG/P worked out of the box
  - Cross compiling is reasonably well supported
    - Still need to do hacky things for hybrid builds
  - Compare to libtool!

We have developed a wrapper generator to speed generation of boilerplate code in PMPI

```
#define swap_comm(comm) \
    if (comm == MPI_COMM_WORLD) comm = virtual_comm;

{{fnall fn_name}}
    {{apply_to_type MPI_Comm swap_comm}}
{{endfnall}}
```

Communicator virtualization in 5 lines with wrap.py

- **wrap.py: LLNL Wrapper Generator**
  - Based on wrapper generator in MPE toolkit (came with MPICH 1)
  - Extensible
    - written in python; each wrap.py macro is a python function.
  - Used extensively in the P^{N}MPI build
  - Adopted by Allinea for use in DDT debugger

Basic wrapper generation

Simple code for timing all functions

```
{{fnall foo MPI_Send MPI_Recv}}
  double start_time = get_time_in_nanoseconds();
  {{callfn}}
  double end_time = get_time_in_nanoseconds();
  printf("{{foo}} took %f nanoseconds to run!\n", (end_time - start_time));
{{endfnall}}
```

Wrap just a couple functions to store their addresses in a global:

```
{{fn foo MPI_Send MPI_Recv}}
  // 'foo' here evaluates to just the name of the function.
  my_global_function_pointer = {{foo}};
  {{callfn}}
{{endfn}}
```

- **wrap.py parses mpi.h and extracts info on types, args, of declarations**
  - Has some a priori knowledge
  - Doesn’t require extra prototype files with descriptions of functions
- **Generates both C and Fortran bindings for same functions**
  - Handles special cases like Fortran mpi_init.

Generating non-wrapper code for each MPI function

Generate enum ids for each MPI function

```
typedef enum {
  {{forallfn foo}}
    {{foo}}_id,
  {{endforallfn}}
} mpi_fn_id_t;
```

String ids for all functions

```
{{forallfn foo}}
static const char *{{foo}}_name = “{{foo}}”;
{{endforallfn}}
```

- **These don’t generate wrappers**
  - Allow same iteration over prototypes and type/arg information
- **Can also use these to generate non-C code**
  - Used by Allinea to generate XML API description files for DDT

Simple syntax for lists and list expressions

Simple list of strings

```
{{list foo bar baz}}
```

Some built in lists, and indexing them for particular elements:

```
// Formal params:
{{formals}}
{{formals 0}}
{{formals 1}}
```

```
// Types of formals:
{{types}}
{{types 0}}
{{types 1}}
```

```
// Argument names:
{{args}}
{{args 0}}
{{args 1}}
```

Substitution, and filtering lists with regular expressions:

```
// Get a list of only those formal parameters that have MPI handle types:
{{filter '^MPI_' {{formals}} }}

// replace void with FOO in the first type in the parameter list
{{sub {{types 0}} void FOO}}

// replace any MPI type with MPI_Foo in the parameter list
{{ret_type}} {{foo}}({{zip {{sub {{types}} 'MPI_.*' MPI_Foo}} {{args}} }});
```

wrap.py is easy to extend

```
#define swap_comm(comm) \
    if (comm == MPI_COMM_WORLD) comm = virtual_comm;

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{{endfnall}}
```

Communicator virtualization in 5 lines with wrap.py

- Above code swaps out MPI_COMM_WORLD for another communicator
- Allows applications to run in a subpartitionof their MPI allocation
- Easy to implement in Python
  - Other such functions can be added quickly

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```

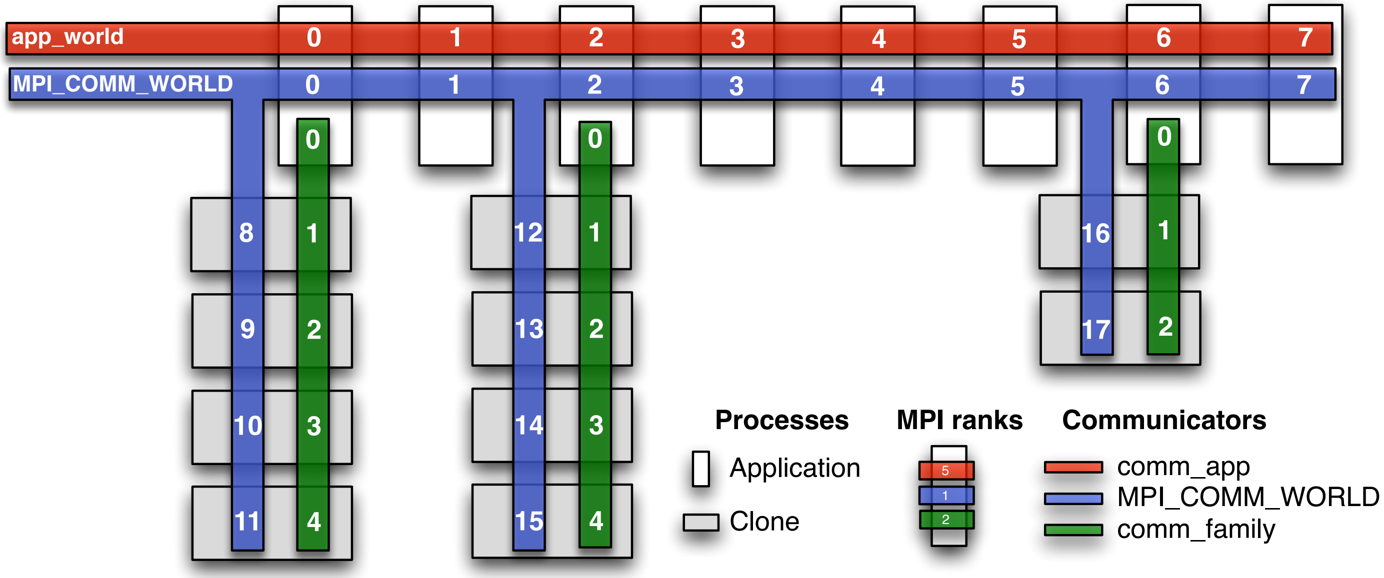
Communicator virtualization in 5 lines with wrap.py

```
class TypeApplier:
    """This class implements a Macro function for applying something
       callable to args in a decl with a particular type.
    """
    def __init__(self, decl):
        self.decl = decl

    def __call__(self, out, scope, args, children):
        len(args) == 2 or syntax_error("Wrong number of args in apply.")
        type, macro_name = args
        for arg in self.decl.args:
            if arg.cType() == type:
                out.write("%s(%s);\n" % (macro_name, arg.name))
```

Python code that implements above macro

We are looking into convenient ways to add more semantics to wrappers



- **MPIEcho** tool was developed in ~2 weeks using wrap.py
  - Allows MPI ranks to be cloned so that heavyweight instrumentation can be spread out
  - Implemented with simple PnMPI virtualization modules in tool stack
- Tool needs semantics of MPI operations in addition to wrapper generation
  - Specific information about args (in parameters, out parameters etc).

Current and Future Projects

- Preparing releases of a number of tool frameworks components using build system described here
  - P^{N}MPI
  - Muster scalable clustering library
  - Nami Wavelet compression library
  - Generic, annotatable Call Tree library
  - Effort library for modeling source code phases/regions
  - Others
  - Libraries used by PAVE project
    - BG/P counters
    - Communication measurement and collective modeling
  - Libraries used by debugging tools
    - Online control flow modeling
- We are extending wrap.py for:
  - Richer semantic information about specific APIs available in the wrapper generator
  - Generic interception of other language runtimes
    - e.g. given a header, wrap every function in it