Open MPI: Overview / Architecture

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CISCO

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Purpose

- An *overview* of Open MPI development
  - There's too much detail for 2 hours
- This is *not* a comprehensive guide!
  - You still need to go explore
  - You still need to go read code
  - You still need to go try things

Overview

- Overview of MPI
- Version Numbers
- Building / Installing Open MPI
- Open MPI Code Architecture
- Run-Time Parameters
- Common Code Highlights
- Hardware Locality ("hwloc")

MPI Goals

MPI goals

- High-level network API
  - Abstracts away the underlying transport
  - Simple things are simple
- API designed to be “friendly” to high performance networks
  - Ultra low latency (*nanoseconds* matter)
  - Rapid ascent to wire-rate bandwidth

MPI goals

- Typically used in High Performance Computing (HPC) environments
  - Has a bias for large compute jobs
- But:
  - "HPC" definition is evolving
  - MPI starting to be used outside of HPC
  - …because MPI is a good network IPC API

Open MPI Version Numbers

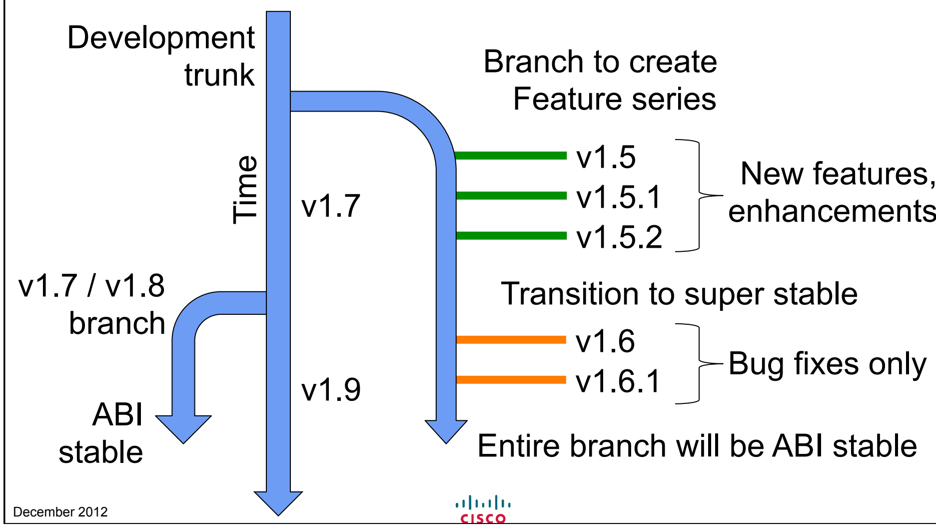
Versioning scheme

- Scheme: <major>.<minor>.<release>
- Open MPI has 2 concurrent release series
  - <minor> = odd: "Feature series"
  - <minor> = even: "Super stable series"
- Both are tested and QA'ed
  - Main difference between the two is time
  - "Stable" series are mature, time-tested

Branch goals

- Trunk: active development
  - "Mostly stable"
- <minor> = odd: feature series (branches)
  - New features added / removed
  - Controlled commits
- <minor> = even: stable series (branches)
  - Bug fixes only – no new features
  - Controlled commits

Feature / stable series



Version control

- Main Open MPI repository is Subversion
  - Hosted by Indiana University (thank you IU!)
  - https://svn.open-mpi.org/svn/ompi

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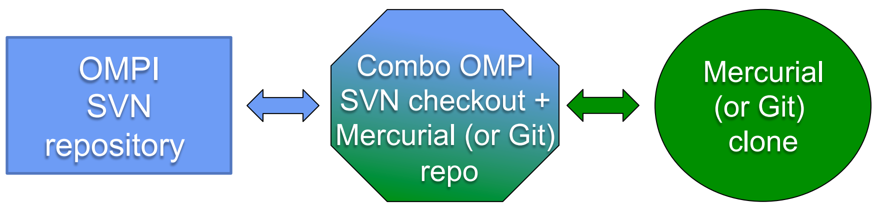
…but you can use others

- Many Open MPI devs use Mercurial or Git
  - …and still stay in sync with SVN
- Excellent for internal development

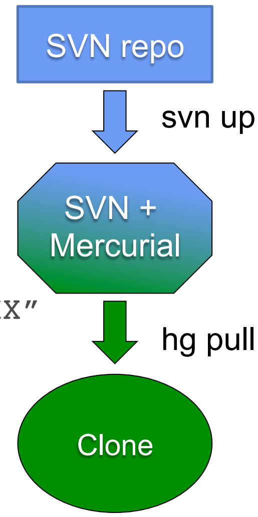


Using Mercurial (or Git)

```
$ svn co https://svn.open-mpi.org/svn/ompi/trunk
    ompi-svn-combo
$ cd ompi-svn-combo
$ hg init
$ cp contrib/hg/.hgignore .
$ hg add
$ ./contrib/hg/build-hgignore.pl
$ hg commit –m “Initial SVN rXXXX version”
$ cd ..
$ hg clone ompi-svn-combo my-work-clone
```

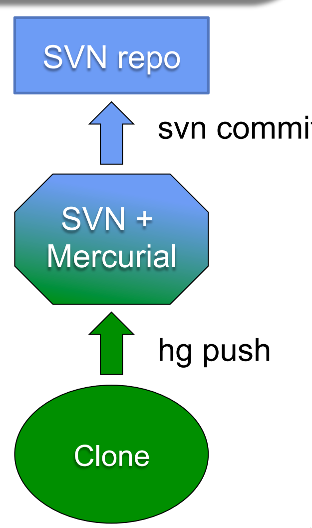
Pull down new SVN commits

```
$ cd ompi-svn-combo
$ hg up
$ svn up
```
→ Merge and resolve any conflicts
```
$ ./contrib/hg/build-hgignore.pl
$ hg addremove
$ hg commit -m "Up to SVN rXXXX"
$ cd ../my-work-clone
$ hg pull
```



Push up Mercurial commits

```
$ cd my-work-clone
…do work…
$ hg commit
$ hg push
$ cd ../ompi-svn-combo
$ hg up
```
→ Merge and resolve any conflicts
```
$ svn commit
```



Using Mercurial (or Git)

- Only use the combo for pushing / pulling!
  - Do development work in clones

- See more details on the Open MPI wiki:
  https://svn.open-mpi.org/trac/ompi/wiki

Building / Installing Open MPI

Distribution tarballs

- Built / installed very much like many other open source packages

```
$ ./configure —prefix=$HOME/ompi …
$ make —j 8 install
```


Filesystem time

- Build machine must be time-synchronized with the file server
  - If building on a local filesystem, non-issue
  - If building on a network filesystem, check this
- **WARNING:**
  - If not synced, strange build errors will occur

Suggestions where to install

- Install somewhere under $HOME
  - No root permissions necessary
- Install on a networked filesystem
  - Available on all servers
- Install to a directory by itself
  - Easy to get a clean, fresh installation

```
$ rm –rf $HOME/ompi; make install
```


Build features

- Parallel builds fully supported

```
$ make –j 8 all
```

- VPATH builds fully supported

```
$ mkdir build
$ cd build
$ ../configure … && make –j 8 …
```

- Common make targets supported
  - all, install, uninstall, clean, distclean, dist, check, …etc.

Building

- Generally only need compilers and “make”
- Defaults to gcc, but can use others

```
./configure CC=icc CXX=icpc FC=ifort …
```

- Many different configure options available

```
./configure --help
```

- Recommend building on a fast (local) disk

Sidenote: save your output!

- *Highly* recommend saving all output
  - You never know if you’ll need to examine something later

```
$ ./configure … 2>&1 | tee config.out
$ make –j 8      2>&1 | tee make.out
$ make install   2>&1 | tee install.out
```

Common configure options

- `--disable-dlopen`
  - Slurp plugins into main libs
- `--enable-mpirun-prefix-by-default`
  - Helps when using ssh
- Disable building optional parts of OMPI
  - `--disable-mpi-cxx`
  - `--disable-mpi-fortran`
  - `--disable-vt`
- `--enable-mpi-java`: Java MPI bindings

Common configure options

- Tell configure non-default locations:
  - `--with-<PACKAGE>=DIR` *(general form)*
  - `--with-jdk-dir=DIR`
  - `--with-verbs=DIR`
  - `--with-valgrind=DIR`
- General philosophy:
  - If configure finds X, build OMPI support for it
  - If configure does not find X, skip it
  - If you ask for X and OMPI does *not* find it, error

Platform files

- Roll up lots of configure options in a file
  - Simple text file with one option per line:

```
enable_mpi_java=yes
enable_vt=no
with_verbs=/usr/local/ofed
```

- Specify via --with-platform:

```
$ ./configure —with-platform=\
    greenplum/mrplus/linux
```


Developer builds

- Require more tools / setup
- SVN trunk currently requires (Dec. 2012):
  - Autoconf 2.69
  - Automake 1.12.2
  - Libtool 2.4.2
  - Flex 2.5.35 (2.5.35 strongly recommended)
- Why?
  - Old Autotools versions have bugs
  - OMPI uses new Autotools features

Don't have recent enough Autotools?

- Easy to obtain and install
  - Download from ftp.gnu.org

```
$ ./configure --prefix=$HOME/gnu
$ make install
```

- **WARNINGS:**
  - You *may* need to install recent GNU m4, too
    - Recent Autoconf versions require recent GNU m4
  - Install all the tools into a single prefix
  - Do *not* overwrite system-installed Autotools!

Developer builds

- Make sure Autotools are in your $PATH
- Run `./autogen.pl` in OMPI top directory
  - More on this script later

- Now `./configure` and `make` just like distribution tarballs

Developer builds

- *Much* debugging is enabled by default
  - Auto-activated if `./configure` sees `.svn`, `.hg`, or `.git` directory
  - Results in lower performance
  - …but (much) easier to debug
- To create an optimized build, either:
  - Build from a distribution tarball, or
  - Do a VPATH build, or
  - Configure `--with-platform=optimized`

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The role of `autogen.pl`

- Prepares the tree and runs the Autotools
  - Takes a minute or three to run
  - You do *not* need to run it every build
- Generally only need to run `autogen.pl`:
  - If you change `VERSION`
  - If you change `configure.ac`
  - If you change any `*.m4` file
  - If `svn up` changes any of these files

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The role of `configure`

- Tests system and prepares to build
  - Configures all plugins and subsystems
  - May take multiple minutes to run
  - You do *not* need to run it every build
- Generally only need to run `configure`:
  - If you re-run `autogen.pl`
  - If you add / remove a framework or plugin

The role of `make`

- Generates a *small* number of source files
  - Flex parsers
  - Fortran modules
- Auto-generate C header dependencies
  - If you edit a C .h file, a top-level `make` will rebuild everything that includes that .h file
- Build and install Open MPI

Where to run `make`

- Top-level directory
- Top-level project directories
  - Only sometimes – more on this later
- Individual plugin directories
  - This saves a *lot* of time
- Popular targets:
  - all, install

What gets installed

- What users need to compile/run MPI apps
- Libraries, plugins, MPI header files
  - E.g., mpi.h, mpif.h, mpi.mod, mpi_f08.mod
- Text config and help files
- Man pages
- Open MPI utility executables
  - E.g., mpicc, mpirun, etc.

What does not get installed

- NO: Autoconf-generated config.h files
- NO: component header files
- NO: project core header files
- NO: libtool convenience libraries

→ If it isn't needed to compile / run MPI apps, it does not get installed

Open MPI Code Architecture

Included 3rd party packages

- Hardware Locality (hwloc)
  - Server topology / locality information
- libevent
  - File descriptor, timer, signal event engine
- libltdl (part of GNU Libtool)
  - Portable “dlopen”, “dlsym”, etc.
- VampirTrace
  - Optional MPI trace library

→ All are configured / built as part of OMPI

Code breakdown

- Vast majority of code base is C
  - A few Flex (.l) files that generate C
- Lots of m4 / sh / Autoconf / Automake
  - Configure / build system only
- A few others
  - MPI Fortran, C++, Java bindings
    - Top-level APIs only; mostly call C underneath
  - Soon: Perl/Python to generate Fortran code

Code breakdown from ohloh.net

Language	LOC	Percent
C:	572,312	74.0%
C++:	58,566	7.6%
Autoconf:	48,923	6.3%
Shell script:	30,520	3.9%
Fortran:	23,121	3.0%
Automake:	12,829	1.7%

Code style guidelines

- 4 space tabs
  - Spaces, not tabs
- Curly braces on first line of the block
  - if (a < b) { …
- Preprocessor macros in all upper case
- Not many other style rules enforced
  - Too much religious debate; not worth it

Defensive programming

- All blocks use curly braces
  - Even one-line blocks
- Constants on the left side of ==
  - if (NULL == foo) { …
- Functions with no arguments are (void)
- No C++-style comments in C code
  - No GCC extensions except in GCC-only code
- No C++ code in libraries
  - Discouraged in components

Defensive programming

- Always define preprocessor macros
  - Define logicals to 0 or 1 (vs. define or not define)
  - Use "#if FOO", not "#ifdef FOO"
  - Gives compiler assistance for mistakes
- Not possible for some generated macros
  - Autoconf and friends

Name conventions

- No CamelCase
- Use multi-word names
  - (Usually) Use full words, not abbreviations
  - Separated by underscores

    `orte_plm_base_receive_process_msg()`

    `opal_hwloc_base_get_local_cpuset()`
- Yes, they're long
  - But you know exactly *what* and *where* they are

Name conventions

- Type names follow the prefix rule
  (described later)
- Most structs are typedef'ed

  `typedef struct ompi_foo_t { …} ompi_foo_t`
- Typically use the typedef name
  - Type names generally end in `_t`
  - Function pointer typedefs end in `_fn_t`

#include statements

- System files are in <>
  - Most should be protected with macros

```
#if HAVE_UNISTD_H
#include <unistd.h>
#endif
```

- OMPI files in “”
  - Always use full pathname

```
#include “opal/mca/base.h”
#include “ompi/group/group.h”
```


Header files

- Always protect with preprocessor macros

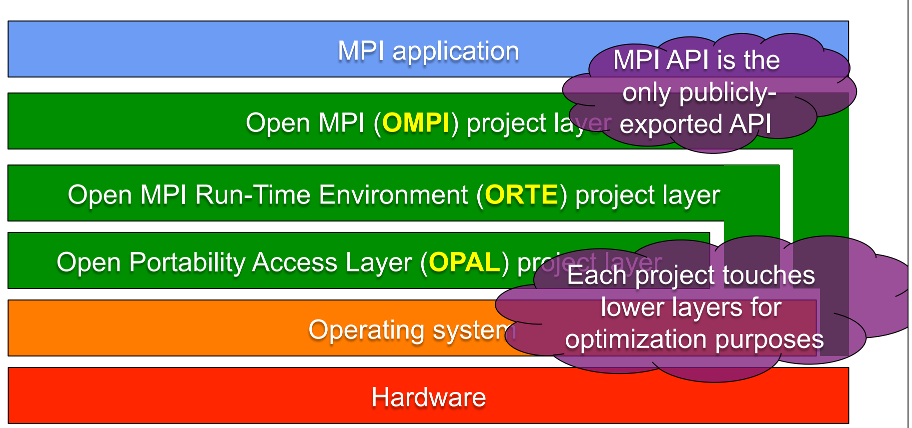
```
#ifndef _THIS_HEADER_FILE_NAME_H
#define _THIS_HEADER_FILE_NAME_H
/* …contents of header file… */
#endif
```

- Only access external symbols through their header files
  - Do not “extern” external variables in .c files
  - Do not prototype external functions in .c files

Compiler warnings

- Fix warnings on all platforms, compilers
- Default GCC developer build
  - Maximum pickyness
- Exceptions granted where warnings cannot be avoided, such as:
  - OpenFabrics header files
  - Flex-generated code

Project architecture view



Projects (layers)

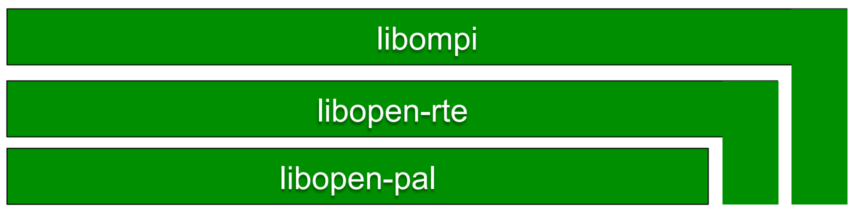
- OMPI *(pronounced: oom-pee)*
  - Public MPI API
  - Back-end MPI semantics and supporting logic
- ORTE *(pronounced: or-tay)*
  - No knowledge of MPI
  - Parallel run-time system
    - Launch, monitor individual processes
    - Group individual processes into "jobs"
  - Forward stdin / stdout / stderr

Projects

- OPAL *(pronounced: o-pull)*
  - Single-process semantics only
  - Portable OS-level functionality
  - Basic utilities (linked lists, etc.)

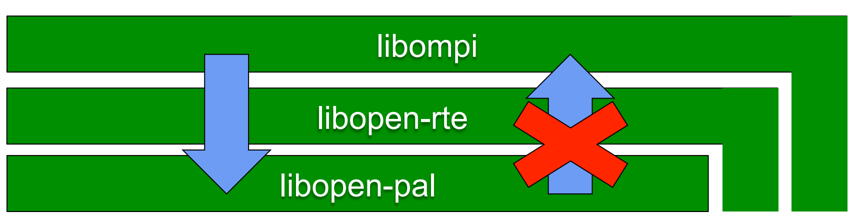
Project separation

- Each project is a separate library



Dependencies

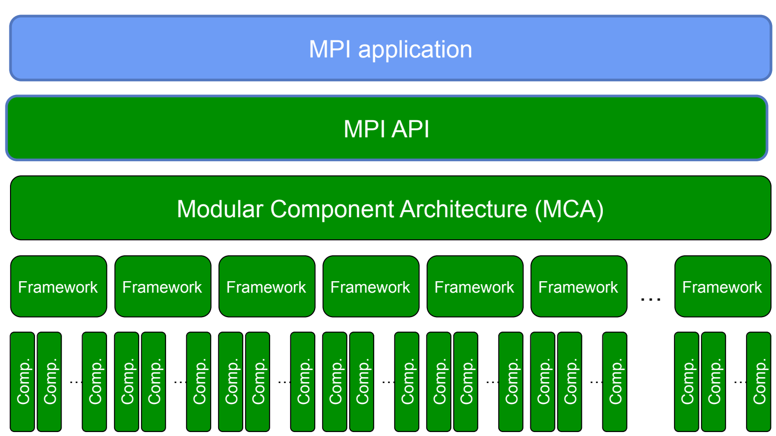
- Downward only!
  - Violations punished by the linker



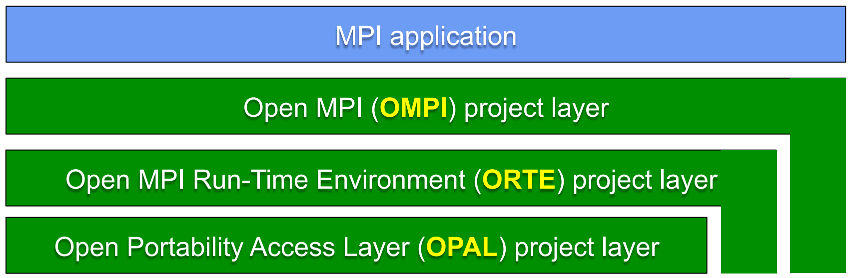
Plugin architecture

- Each project is structured similarly:
  - Main / core code
  - Components (a.k.a. “plugins”)
  - Frameworks
- Plugins are a fundamental design decision
  - Governed by the Modular Component Architecture (MCA)

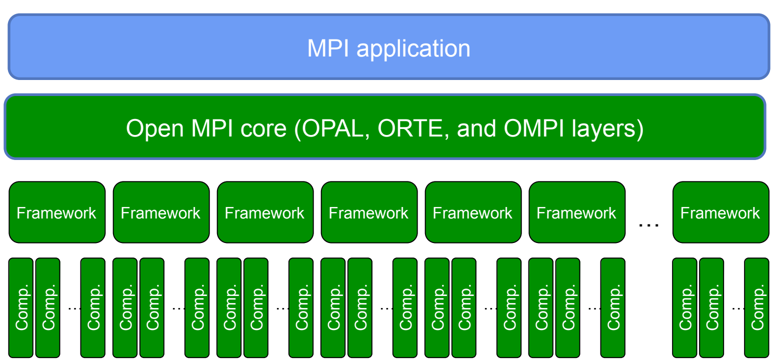
MCA architecture view



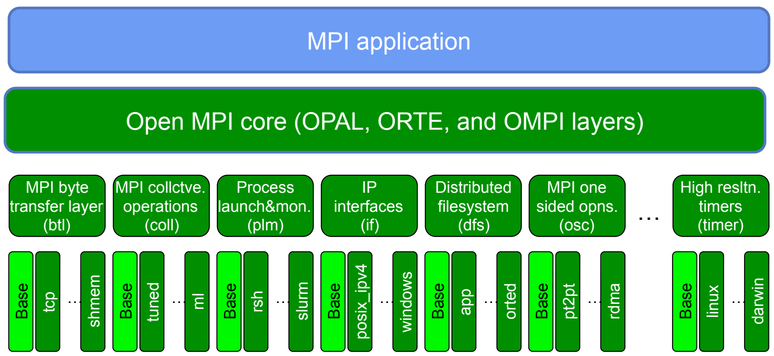
Project architectural view (for comparison)



Merged architecture views



Merged architecture views, showing some actual frameworks and components



Why components (plugins)?

- Better software engineering
  - Enforce strict abstraction barriers
- Small, discrete chunks of code
  - Good for learning / new developers
  - Easier to maintain and extend
- Separate user apps from back-end libraries
  - E.g., MPI apps not compiled against libibverbs.so / libportals.so / libpbs.a

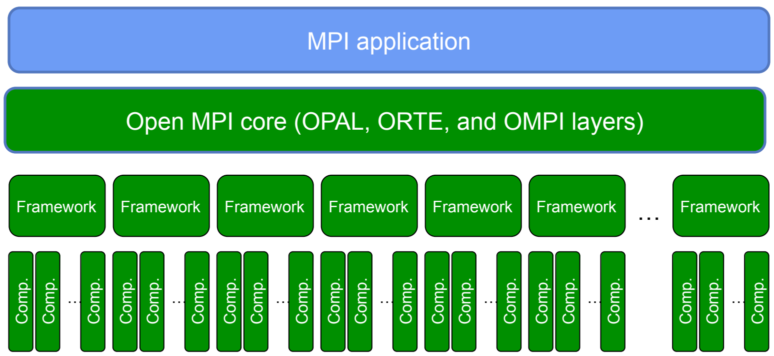
MCA layout

- MCA
  - Top-level architecture for component services
  - Find, load, unload components
- Frameworks
  - Targeted set of functionality
  - Defined interfaces
  - Essentially: a grouping of one type of plugins
  - E.g., MPI point-to-point, high-resolution timers

MCA layout

- Components
  - Code that exports a specific interface
  - Loaded / unloaded at run-time (usually)
  - Think "plugins"
- Modules
  - A component paired with resources
  - E.g., "TCP" component loaded, finds 2 IP interfaces (eth0, eth1), makes 2 TCP modules

Merged architecture views (review)



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MCA code organization

- Frameworks
  - Have unique string names
- Components
  - Belong to exactly one framework
  - Have unique string names
  - Namespace is per framework
- All names must be valid C variable names

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Organized by directory

- <project>/mca/<framework>/<component>
  - Project = opal, orte, ompi
  - Framework = framework name, or "base"
  - Component = component name, or "base"
- Directory names must match
  - Framework name
  - Component name
- Examples
  - ompi/mca/btl/tcp, ompi/mca/btl/sm

"Base"

- Reserved name: "base"
  - opal/mca/base: the MCA itself
  - orte/mca/plm/base: the PLM framework
  - ompi/mca/btl/base: the BTL framework
- Helper functions / header files
  - Common to all components in that framework
  - Public data / methods to be invoked from outside the framework

Directory layout

top →
- configure
- README
- NEWS
- VERSION
- …others…
- ompi
- orte
- opal

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Directory layout

top →
- configure
- README
- NEWS
- VERSION
- …others…
- ompi
- orte
- opal →
  - asm
  - class
  - config
  - datatype
  - …others…
  - mca

OPAL
project tree

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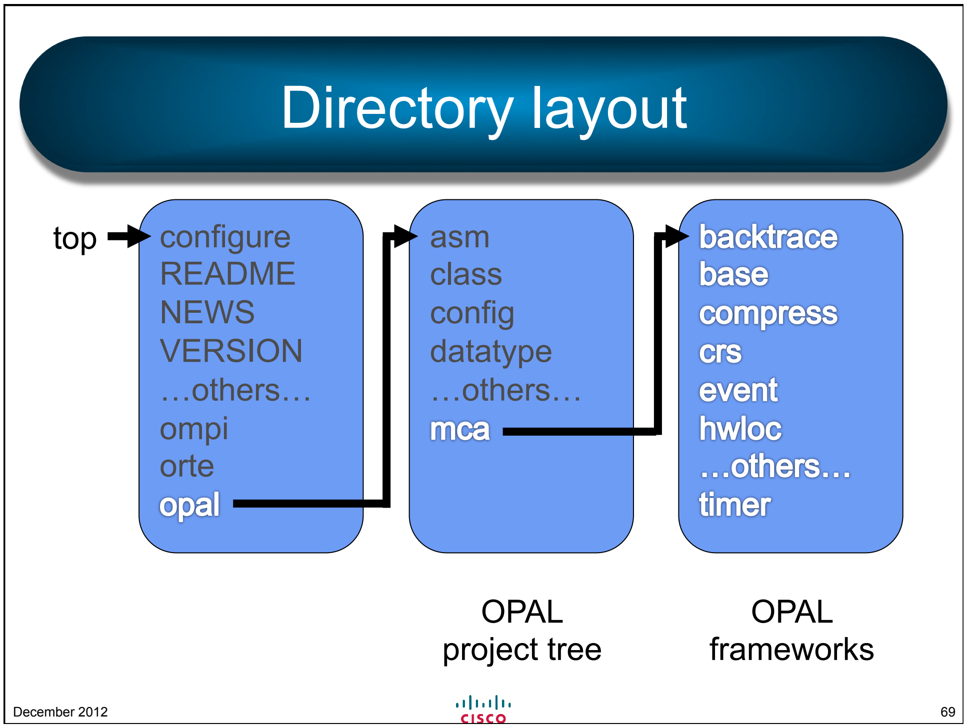
Directory layout
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OPAL project tree
OPAL frameworks
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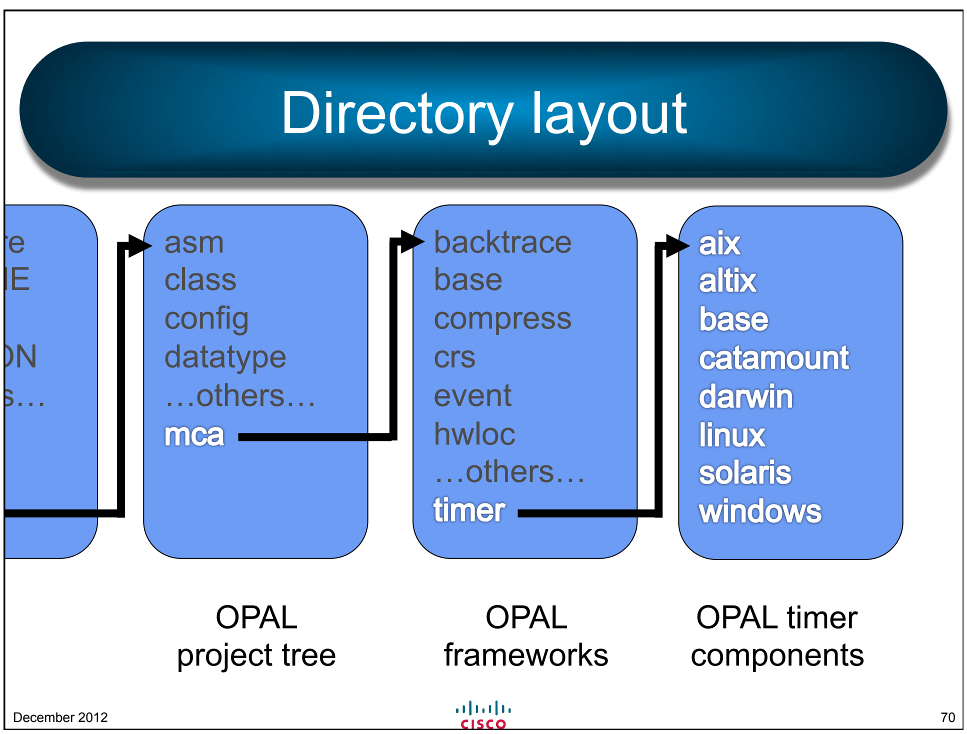
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OPAL timer components
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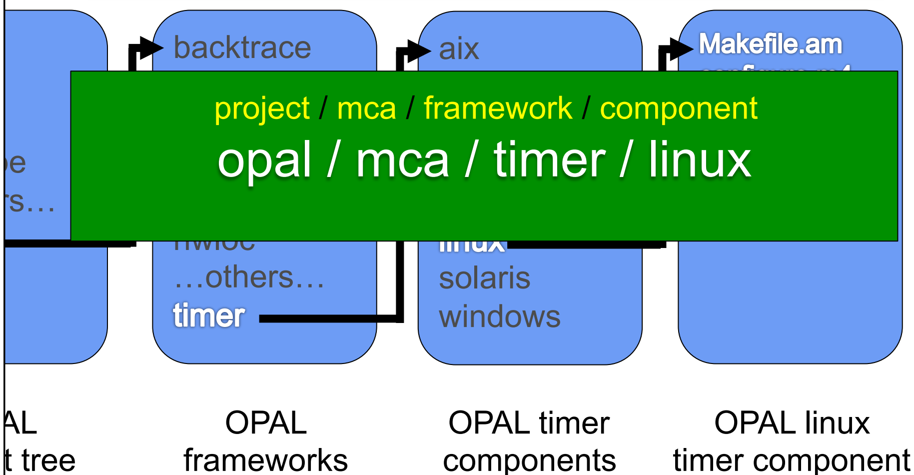
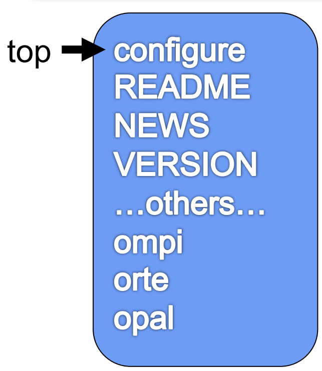
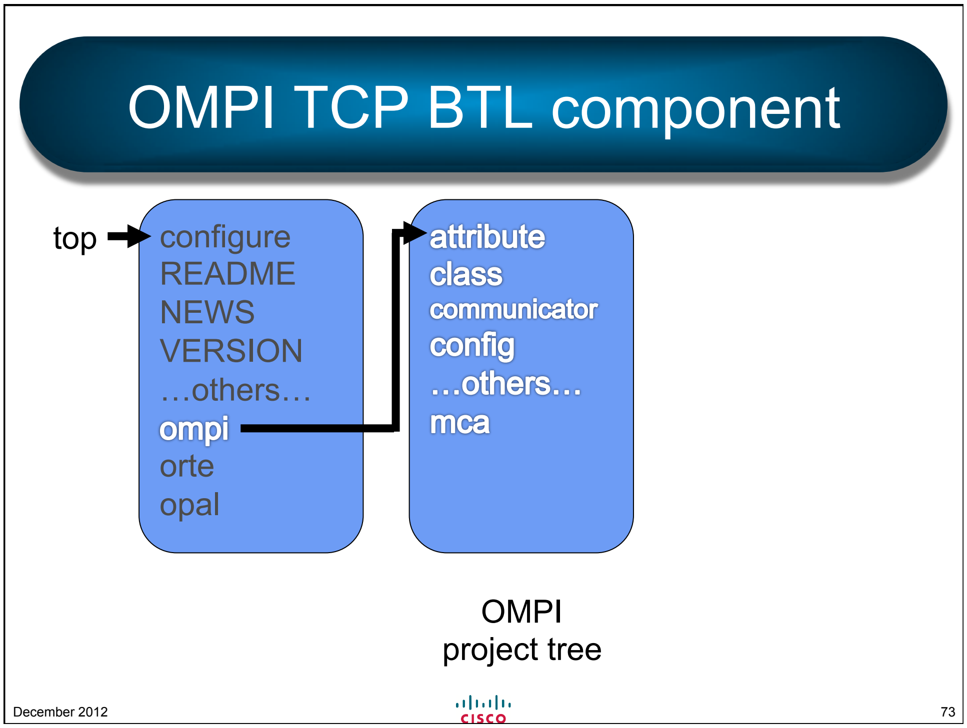
OPAL Linux timer compoment



OMPI TCP BTL component

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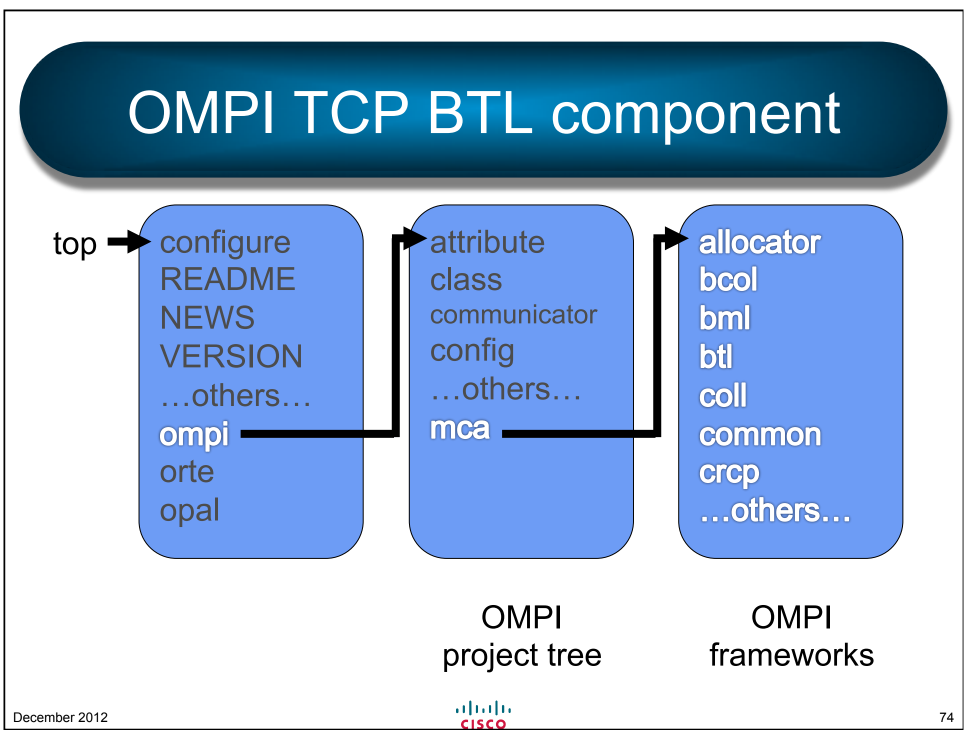
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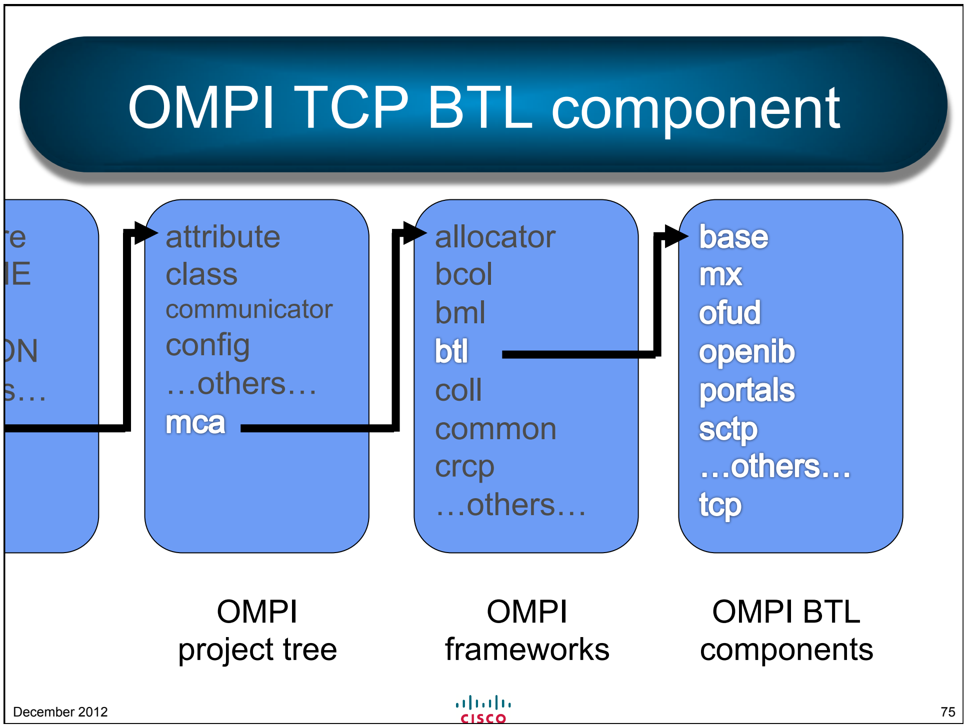
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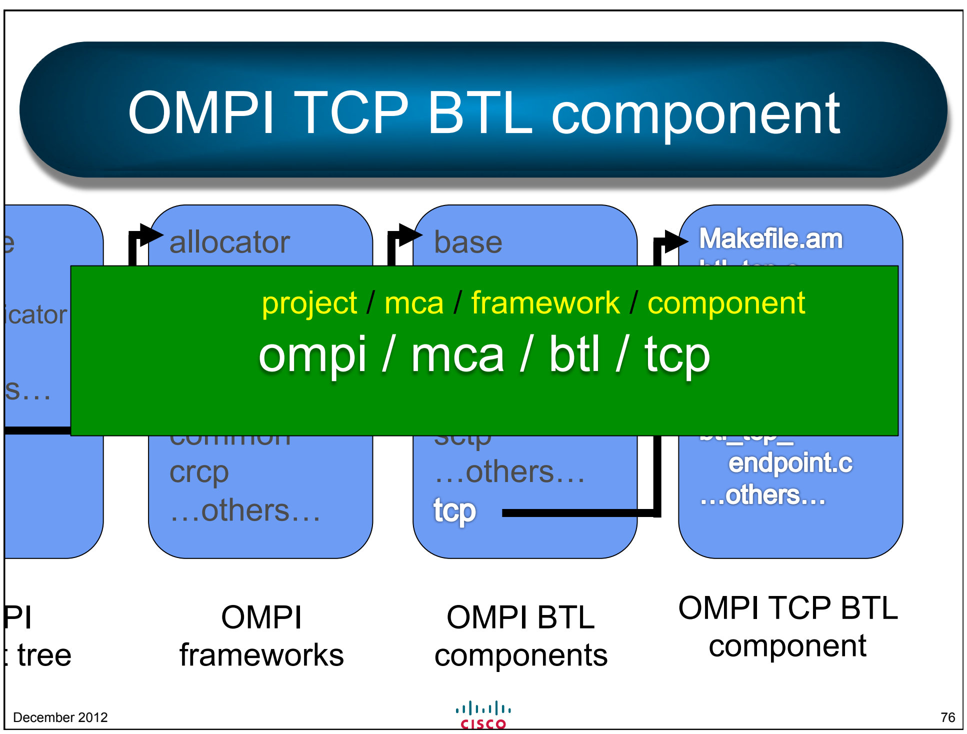
OMPI TCP BTL component
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Makefile.am
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…others…
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endpoint.c
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frameworks
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OMPI TCP BTL
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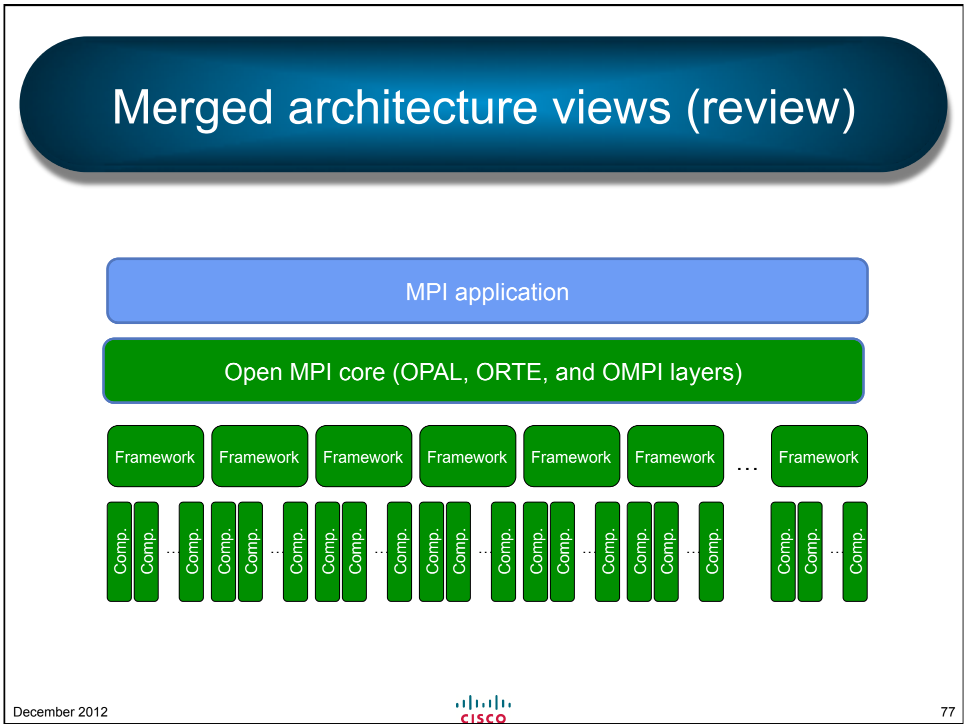
Merged architecture views (review)
MPI application
Open MPI core (OPAL, ORTE, and OMPI layers)
Framework
Framework
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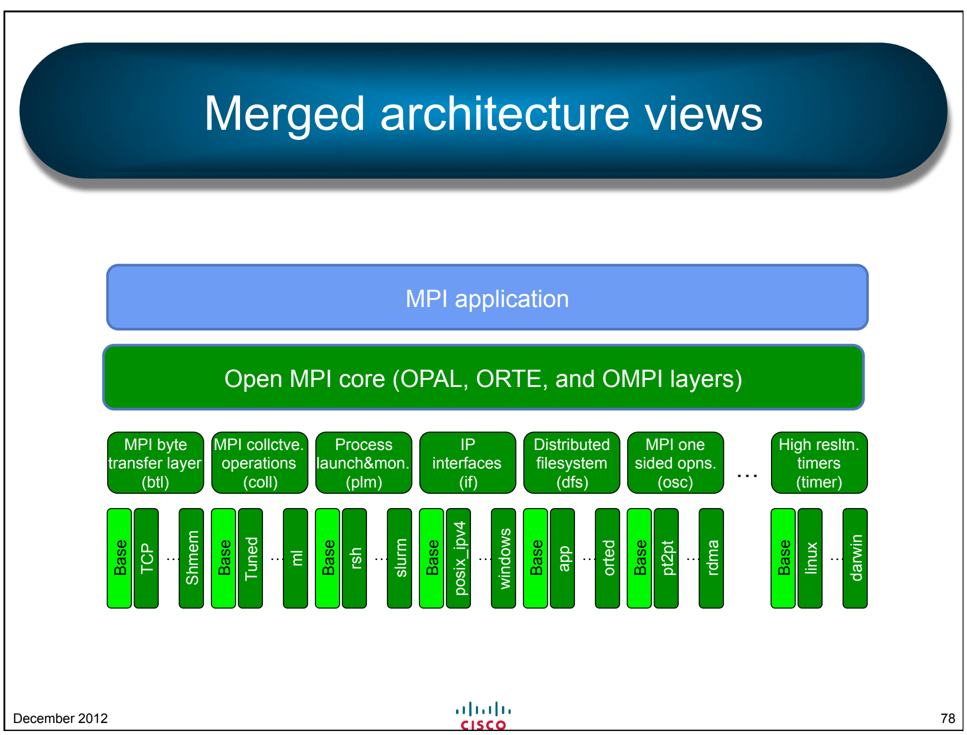
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MPI application
Open MPI core (OPAL, ORTE, and OMPI layers)
MPI byte transfer layer (btl)
MPI collctve. operations (coll)
Process launch&mon. (plm)
IP interfaces (if)
Distributed filesystem (dfs)
MPI one sided opns. (osc)
…
High resltn. timers (timer)
Base
TCP
Shmem
Base
Tuned
ml
Base
rsh
slurm
Base
posix_ipv4
windows
Base
app
orted
Base
pt2pt
rdma
Base
linux
darwin
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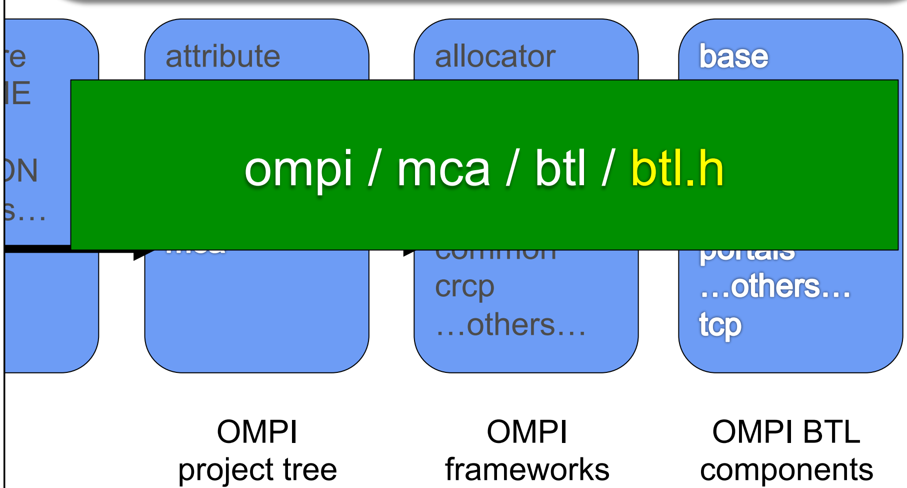
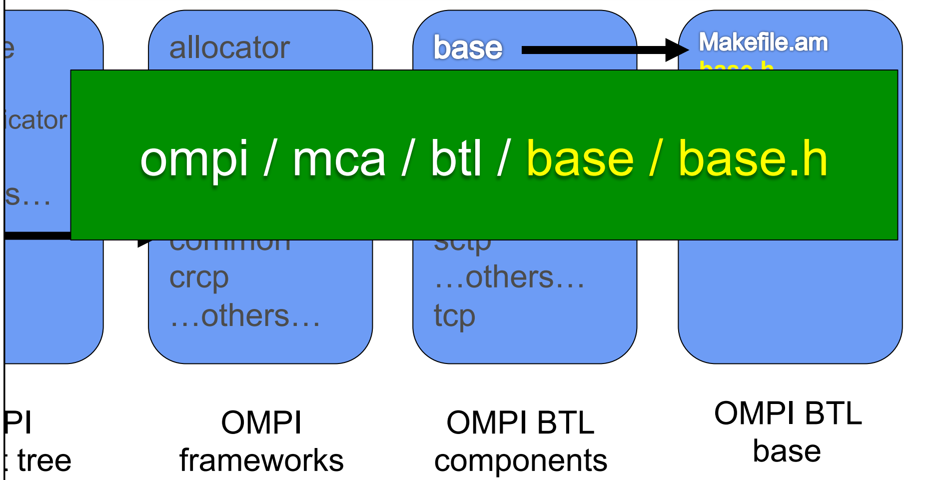
Header File Conventions

- Framework interface defined in
  - <project>/mca/<framework>/<framework>.h
  - This is mandatory
- Public base functions declared in
  - <project>/mca/<framework>/base/base.h
  - This is common, but not mandatory

BTL framework header



BTL base public header



Components

- Back-end component magic
  - Function pointers
  - Usually compiled as dynamic shared objects (DSO’s) in .so files (“plugins”)
  - But can be included in libmpi (etc.)
- Use GNU Libtool “ltdl” library
  - Portable dlopen(), dlsym()
  - Even works on Windows
  - Not GPL (!)

Component implementations

- Build system requirements:
  - `configure.m4`
  - `Makefile.am`
  - Will not discuss these in detail today
- Details of component build requirements:

  https://svn.open-mpi.org/trac/ompi/wiki/devel/CreateComponent

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Component implementations

- Freedom of implementation
  - As many `.c` and `.h` files as you want
  - Can even have subdirectories
- End result, needs to produce `mca_<framework>_<component>.so`
  - Examples

    `mca_btl_tcp.so`

    `mca_plm_rsh.so`

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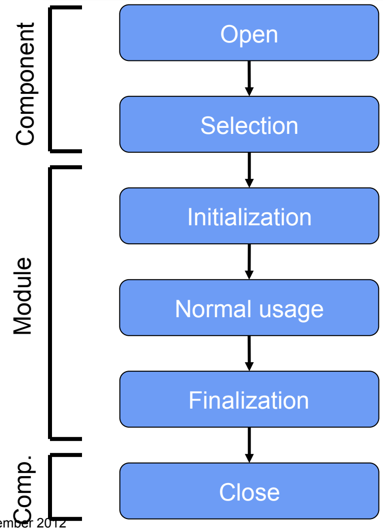
Each framework is unique

- The MCA base is strictly defined
- Each framework builds upon the base
  - But definitions are framework-specific
  - Every framework is different
  - Depends on what the framework is for
- Therefore somewhat difficult to describe
- But most follow common conventions

Component Interface

- Defined by the framework
- Typically has some kind of selection function
- Framework asks each component:
  - "Do you want to be used with X?"
  - Where "X" is relevant to the framework
- Examples
  - BTL: "Do you want to be used with this process?"
  - Coll: "Do you want to be used with MPI communicator X?"

Component / Module Lifecycle

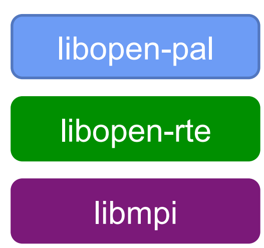


- Component
  - Open DSO (if necessary)
  - Open: per-process initialization
  - Selection: per-scope determination if want to use
  - Close: per-process finalization
  - Close DSO (if necessary)
- Module
  - Initialization: per-scope, if component is selected
  - Normal usage
  - Finalization: per-scope cleanup

Where to run `make` (redux)

- Top-level directory
  - Makes everything

```
$ make all
```



Where to run `make` (redux)

- Top-level directory
  - Makes everything
- Top-level project directories
  - Builds entire project library

```
$ cd opal
$ make all
```

libopen-pal

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Where to run `make` (redux)

- Top-level directory
  - Makes everything
- Top-level project directories
  - Builds entire project library

```
$ cd orte
$ make all
```

libopen-rte

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THIS SLIDE IS OBSOLETE!

After we recorded the video, we made changes to the Open MPI build system that made this slide be incorrect.

Specifically: libopen-rte does *not* include libopen-pal, and libmpi does not include libopen-rte.

So you can "make" in in project directory, and even "make install".

Where to run `make` (redux)

- In individual component directories
  - E.g., `make all` or `make install`
  - Saves a *lot* of time
- Example

```
$ cd ompi/mca/btl/tcp
…modify the TCP BTL…
$ make install
```

More related wiki pages

- The role of autogen.pl
  https://svn.open-mpi.org/trac/ompi/wiki/devel/Autogen
- How to add a component
  https://svn.open-mpi.org/trac/ompi/wiki/devel/CreateComponent
- How to add a framework
  https://svn.open-mpi.org/trac/ompi/wiki/devel/CreateFramework

Framework / component prefix rule

- Public names / symbols must be prefixed
  - `project_framework_component_<name>` (usually)
  - `framework_component_<name>`
  - `mca_framework_component_<name>`
    - Component struct only – special case

Framework / component prefix rule

- **WARNING** (historical note):
  - <project> prefix was only added recently
  - Many component files and symbols do not have <project> prefix
  - All *new* names should be project-prefixed
  - Will be fixed over time

Prefix rule examples

- Public function: `opal_timer_linux_init()`
- Public symbol: `orte_plm_rsh_started`
- Filename: `btl_tcp_component.c`
  - Note lack of <project> -- should be updated!

Prefix rule rationale

- All the .c→.o files exist in a single process
  - Cannot have filename collisions
  - Cannot have symbol collisions (variables, functions, or types)
- Also cannot collide with user app symbols

Prefix rule in project cores

- Outside of frameworks / components
  - Use `<project>` prefix for symbols
  - Subset as appropriate

    Func: `ompi_free_list_init()`

    Variable: `orte_plm_base`

    Type: `opal_list_t`
- Same rationale applies:
  - Avoid symbol collisions in OMPI
  - Avoid symbol collisions with MPI application

Public vs. private symbols

- Remember: this is middleware
  - Only make public what you need to
- OMPI defaults to private symbols
  - Must declare symbols to be public
  - Use “DECLSPEC” macro (per project)

```
ORTE_DECLSPEC bool orte_plm_rsh_started;
```

- Components invoked by function pointers
  - *Most symbols do not need to be public*

Portability

- Beware of Linux / GCC-specific-isms
  - Non-portable code goes in components
  - Or surrounded by `#if`
- All .c files must have code that is *called*
  - Do not have “constants.c” with no functions
  - Some linkers will drop .o’s with no callable code (e.g., OS X)

Run-Time Parameters

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Tunable parameters

- Philosophy: do not use constants
  - Use run-time parameters instead
- Referred to as "MCA parameters"
  - Somewhat misleading name
  - Means: service provided by the MCA base
  - Does not mean that they are restricted to MCA components or frameworks
  - OPAL, ORTE, and OMPI projects have "base" parameters, too

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Rationale

- Make everything a run-time decision
  - Give every param a "sensible" default
  - …where possible
- Parameters usually indicate:
  - Values (e.g., short/long message size)
  - Behavior (e.g., selection of algorithm)
- Much easier than recompiling

Intrinsic MCA param: framework name

- Each framework name is an MCA param
  - Specifies which components to open
- MCA base automatically registers it
  - Comma-delimited list of component names
  - Default value is empty (meaning "all")
- Inclusionary or exclusionary behavior

```
btl=tcp,self,sm
btl=^tcp
```

MCA param lookup order

1. "Override" value (set by API)
2. mpirun command line
   - `mpirun –mca <name> <value>`
3. Environment variable
   - `setenv OMPI_MCA_<name> <value>`
4. File
   - `$HOME/.openmpi/mca-params.conf`
   - `$prefix/etc/openmpi-mca-params.conf`

   (these locations are themselves tunable)
5. Default value

Using MCA parameters

- Characteristics
  - Strings and integers
  - Read-only (information) and read-write
  - Private and public
- **WARNING:** Lookup is slow!
  - Do not put in critical performance path
  - Do lookups at beginning of scope

MCA param examples

- btl_udverbs_version
  - Read-only, string version of the Verbs library that udverbs BTL was compiled against
- btl_tcp_if_include
  - Read-write, string list of IP interfaces to use
- btl
  - Read-write, list of BTL components to use
- orte_base_singleton
  - Private, whether this process is a singleton

Sidenote: `ompi_info` command

- Tells everything about OMPI installation
  - Finds all components and all params
  - Great for debugging
- Can look up specific component
  - `ompi_info --param <framework> <component`
  - Shows params, current values, where set from
  - Can also use keyword "all"
- `--parsable` option

MCA param API

- See `opal/mca/base/mca_base_param.h`
- Register and lookup functions
  - Several variations of each
- Components register params during component register (or open; deprecated)
  - `ompi_info` calls register/open/close on every component that it finds (to discover parameters)

Prefix rule and MCA params

- MCA params must be prefixed
  - Does not include the project name

  <framework>_<component>_<param_name>
- Examples

  `btl_tcp_mtu`

  `coll_basic_bcast_crossover`
- Register API function takes 3 strings
  - When registering in core, use:
    - Framework = project name
    - Component = "base"

Common Code Highlights

Init / finalize

- `<foo>_init()` to initialize something
- `<foo>_finalize()` to finalize something
- Examples:
  - `ompi_mpi_init()`: initializes OMPI layer, calls
  - `orte_init()`: initializes ORTE layer, calls
  - `opal_init()`: initializes OPAL layer
- Paired with `ompi_mpi_finalize()`, etc.
  - Frees resources, etc.

Init / finalize

- Not just used for overall projects
- Also used for individual subsystems

```
ompi_op_init()
  → ompi_op_finalize()
opal_datatype_init()
  → opal_datatype_finalize()
```


Utility code

- `<project>/util/*.[h,c]`
- E.g., OPAL has lots of compatibility code
  - asprintf, qsort, basename, strncpy
- Useful "add-on" code
  - Manipulate argv arrays (opal/util/argv.h)
  - printf debugging code (opal/util/output.h)
  - Error reporting (opal/util/show_help.h)
  - IP interfaces (opal/util/if.h)

Arrays of strings

- See `opal/util/arg.h`: `opal_argv_*()`
- Simple functions for maintaining argv-style arrays of strings
  - Prepend / append (resize if necessary)
  - Insert / remove (resize if necessary)
  - Split / join
  - Get length of array
  - Free array (and all strings)

`opal_output()` debugging code

- Function to emit debugging / error messages to stderr, stdout, file, syslog, …
  - Versions to simplify debugging output
  - Stream 0 prepends host, PID
- Printf-like arguments

```
opal_output(0, "hello, world");
opal_output_verbose(0, 10, "debugging…");
OPAL_OUTPUT(0, "--enable-debug only");
OPAL_OUTPUT_VERBOSE(….);
```

Friendly error messages

- `opal/util/opal_show_help.[h,c]`
- Print friendly messages for users
  - Message in text file rather than in source code
  - Can use printf substitutions (%s, %d, etc.)
  - De-duplicates messages
- Example
  - `opal_show_help(“help-mpi-btl-tcp.txt”, “invalid minimum port”, true, “ipv4”, default_value, hostname, port_num);`

Friendly error messages

- Contents of help-mpi-btl-tcp.txt:

```
[invalid minimum port]
WARNING: An invalid value was given for the
btl_tcp_port_min_%s. Legal values are in the
range [1 .. 2^16-1]. This value will be
ignored; OMPI will use the default value of
%d.

  Local host: %s
  Value:      %d
```

Discover IP interfaces

- See `opal/util/if.h`: `opal_if_*()`
- STL-like iteration over OS IP interfaces
  - Get info about each interface
  - Name, flags, netmask, loopback, etc.

Object system

- C-style reference counting object system
- "Poor man's C++"
  - Single inheritance
  - Constructors / destructors associated with each object instance
- Statically or dynamically allocated objects

Object system example

- Define class in header

```
typedef struct ompi_foo_t   {
  ompi_parent_t parent;
  void *first_member;
  ...
} ompi_foo_t;
OBJ_CLASS_DECLARATION(ompi_foo_t);
```

- `ompi_parent_t` must be a object
  - Root object is `opal_object_t`

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Object system example

- Must instantiate class descriptor in .c file

```
OBJ_CLASS_INSTANCE(ompi_foo_t,
    ompi_parent_t, foo_construct,
    foo_destruct);
```

- Local constructor / destructor functions
  - Both take one param: pointer to the object
- Constructors and destructors called recursively up the object stack

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Dynamic objects

- Create dynamically allocated object
  - Initial reference count set to 1

```
ompi_foo_t *foo = OBJ_NEW(ompi_foo_t);
```

- Increase reference count

```
OBJ_RETAIN(foo);
```

- Decrease reference count

```
OBJ_RELEASE(foo);
```

- Object destroyed and freed when reference count hits 0

Static objects

- Construct object

```
ompi_foo_t foo;
OBJ_CONSTRUCT(&foo, ompi_foo_t);
```

- Destruct object:

```
OBJ_DESTRUCT(&foo);
```

- Can use `OBJ_RETAIN/OBJ_RELEASE`, but
  - "Badness" if reference count hits 0
  - No automatic destruction if object goes out of scope

Object-based containers

- Lists, free lists, hash tables, value array, atomic LIFO list
- OMPI provide additional functionality
  - Shared memory fifo, red-black tree
- Such OBJ-based code usually found in `<project>/class`

Linked List

- `opal_list_t` is a doubly-linked list
- Item ownership transferred
  - No copies like in STL
  - Item only belong to one list
- Pointers to items never invalidated by `opal_list` functions
- O(1) insert, delete, join, get size
- Splice and sort routines
- Large debugging performance impact

…and others

- Go explore:
  - <project>/util
  - <project>/class
- If you find yourself writing “glue” code
  - Look first in util directories
  - If not there, consider if you should put it in util

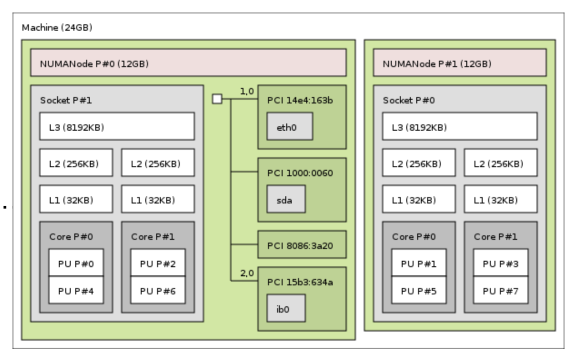
Hardware Locality (“hwloc”)

Hardware Locality (hwloc)

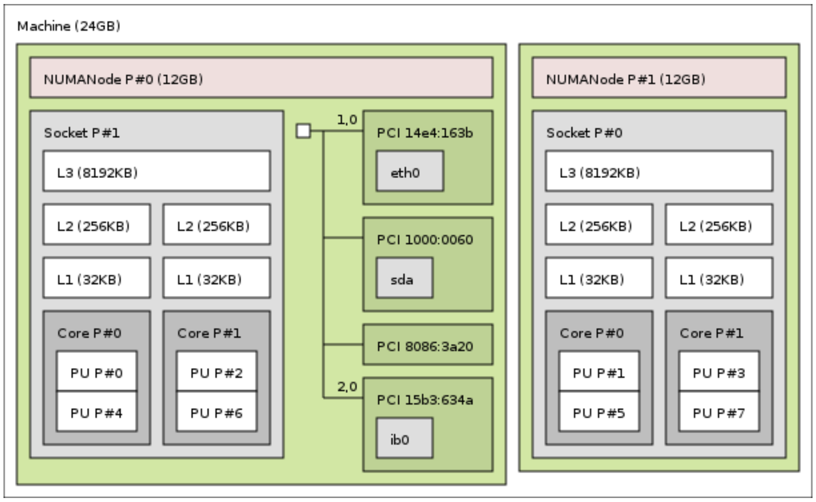
- High performance computing is all about location, Location, LOCATION!
  - NUMA is now common
  - Can consider network as next (several) level(s) of locality: NUNA
- Performant code must understand locality

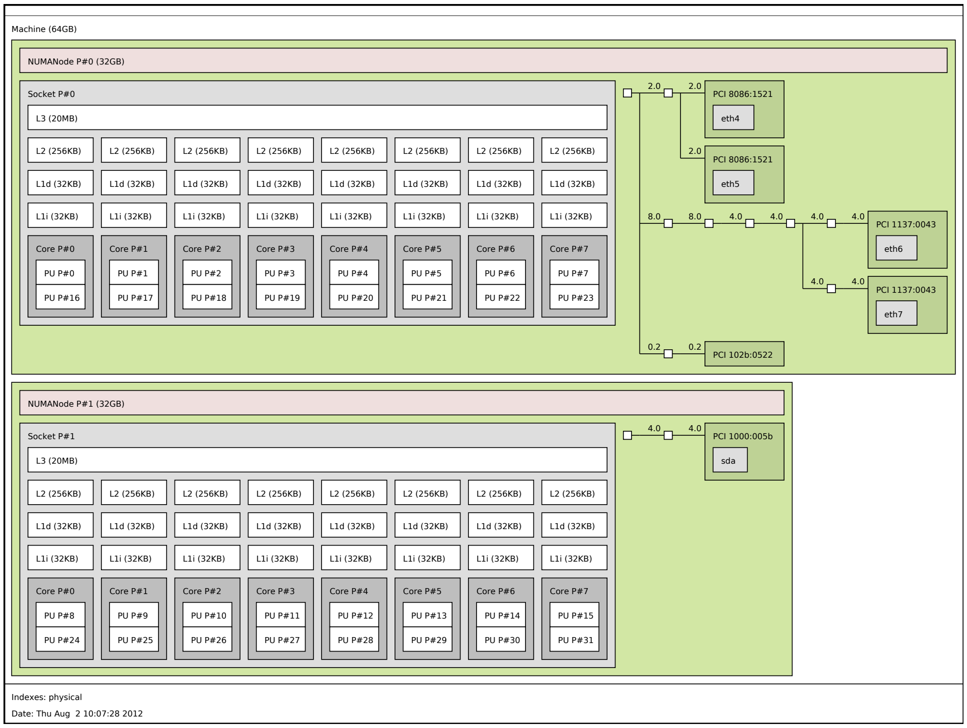
Hardware Locality (hwloc)

- Hwloc provides inside-the-server topology
  - CLI
    - Prettyprint
    - JPG, PNG, PDF, …
  - XML
  - C API
- lstopo(1) draws these pictures



Hwloc example





Hwloc capabilities

- Query topology information
  - As shown in previous pictures
  - C API provides tree of all that information
- Memory and processor affinity
  - hwloc-bind(1) *much mo' betta* than numactl(1)

```
$ hwloc-bind socket:0.core:3 my_program
hwloc_set_cpubind(…)
```

- Works on many different Oss
  - Linux, OS X, Windows, BSDs, …etc.

Hwloc sub-project

- An official sub-project of Open MPI
  - Has its own SVN repository
  - Developed mainly by INRIA (France)
  - A full copy of it is maintained on OMPI's SVN
- Fully documented
  - *Excellent* stand-alone tool (unrelated to MPI)
  - Highly encourage you to check it out

Open MPI's use of hwloc

- Wholly embeds a copy of hwloc
  - Can be compiled to use external hwloc
  - Embedded hwloc is certified to work properly
- Used to discover server topology
  - Effect processor and memory affinity
  - Query cache sizes
  - Query process peer locality (same socket, NUMA node, etc.)
  - Query PCI device locality

Open MPI's use of hwloc

- …and we're just getting started
- Anticipate much more use of the hwloc API over time
  - MPI collective algorithms
  - MPI shared memory point-to-point communications
  - …etc.

Questions?

Thank you!

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