Managing HPC Software Complexity with Spack

Supercomputing 2020 Full-day Tutorial
November 9-10, 2020
Virtual Event

The most recent version of these slides can be found at:
https://spack-tutorial.readthedocs.io

LLNL-PRES-806064

Lawrence Livermore National Laboratory

ECP EXASCALE COMPUTING PROJECT

SC20 Everywhere we are | more than hpc.

Tutorial Materials

Find these slides and associated scripts here:

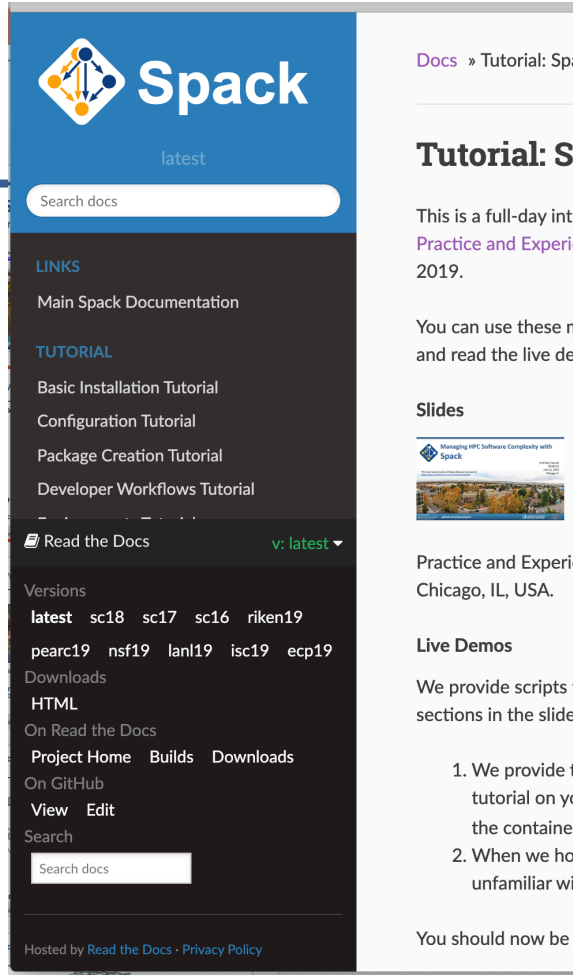
spack-tutorial.readthedocs.io

We will also have a chat room on Spack slack. Get an invite here:

spackpm.herokuapp.com

Join the “tutorial” channel!

We can engage with in-depth questions more directly on Slack!



Tutorial Presenters

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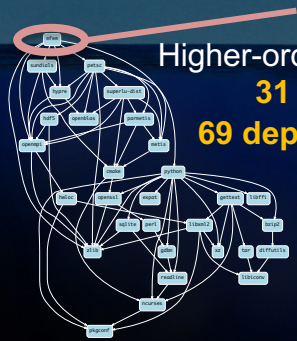
UIUC

Massimiliano
Culpo
NP Complete, S.r.l.

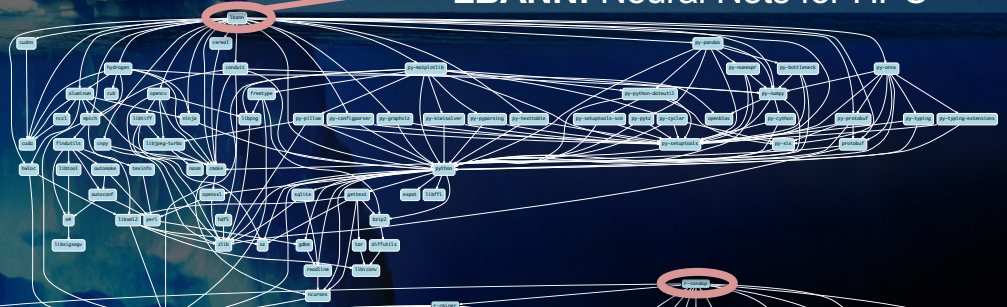
Modern scientific codes rely on icebergs of dependency libraries

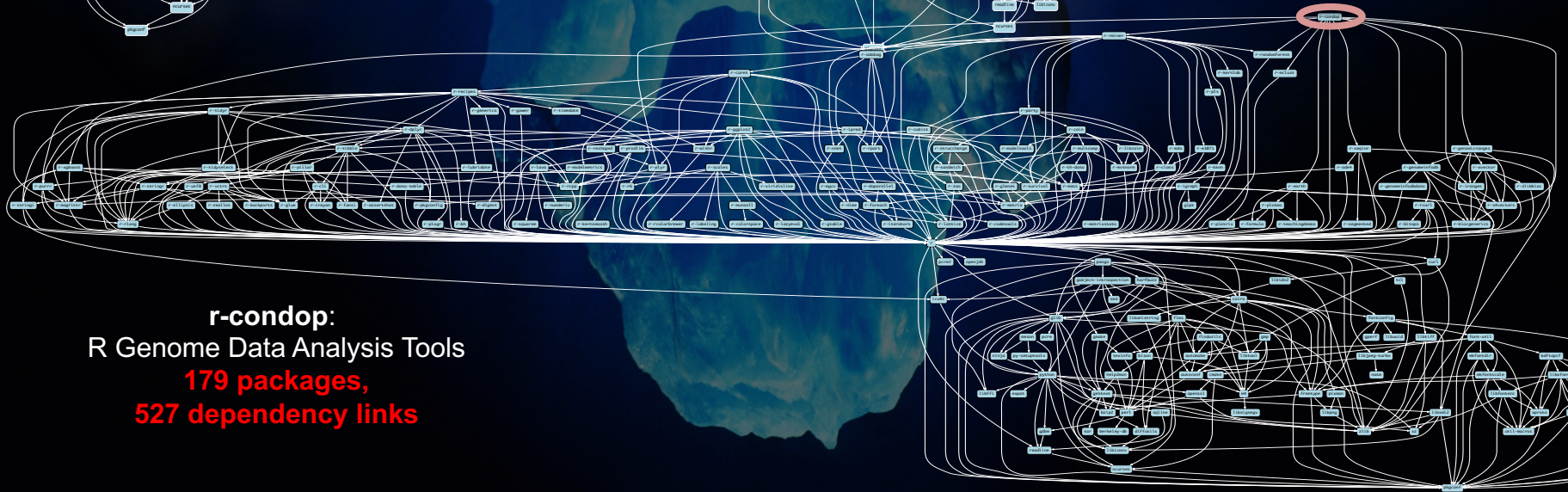
MFEM:
Higher-order finite elements
31 packages,
69 dependency links



71 packages
188 dependency links

LBANN: Neural Nets for HPC





r-condop:
R Genome Data Analysis Tools
179 packages,
527 dependency links

What is the “production” environment for HPC?

- Someone’s home directory?
- LLNL? LANL? Sandia? ANL? LBL? TACC?
  - Environments at large-scale sites are very differen
- Which MPI implementation?
- Which compiler?
- Which dependencies?
- Which versions of dependencies?
  - Many applications require specific dependency versions.

Real answer: there isn’t a single production environment or a standard way to build.
Reusing someone else’s software is HARD.

The complexity of the exascale ecosystem threatens productivity.

15+ applications x **80+ software packages** x **5+ target architectures/platforms**
Xeon Power KNL
NVIDIA ARM Laptops?

x **Up to 7 compilers**
Intel GCC Clang XL
PGI Cray NAG

x **10+ Programming Models**
OpenMPI MPICH MVAPICH OpenMP CUDA
OpenACC Dharma Legion RAJA Kokkos

x **2-3 versions of each package + external dependencies**

= up to **1,260,000** combinations!

- Every application has its own stack of dependencies.
- Developers, users, and facilities dedicate (many) FTEs to building & porting.
- Often trade reuse and usability for performance.

We must make it easier to rely on others' software!

What about containers?

- **Containers provide a great way to reproduce and distribute an already-built software stack**
- **Someone needs to build the container!**
  - This isn't trivial
  - Containerized applications still have hundreds of dependencies
- **Using the OS package manager inside a container is insufficient**
  - Most binaries are built unoptimized
  - Generic binaries, not optimized for specific architectures
- **HPC containers may need to be *rebuilt* to support many different hosts, anyway.**
  - Not clear that we can ever build one container for all facilities
  - Containers likely won't solve the N-platforms problem in HPC

We need something more flexible to **build** the containers

Spack is a flexible package manager for HPC

- How to install Spack:

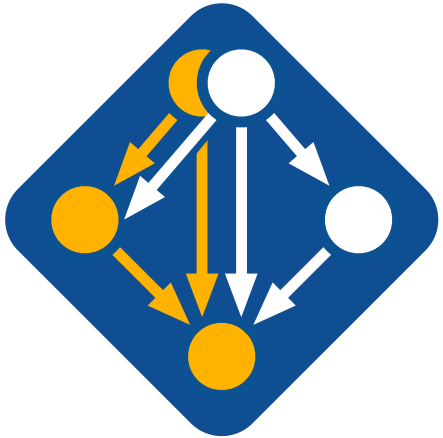
```
$ git clone https://github.com/spack/spack
$ . spack/share/spack/setup-env.sh
```

- How to install a package:

```
$ spack install hdf5
```

- HDF5 and its dependencies are installed within the Spack directory.

- Unlike typical package managers, Spack can also install many variants of the same build.
  - Different compilers
  - Different MPI implementations
  - Different build options



github.com/spack/spack

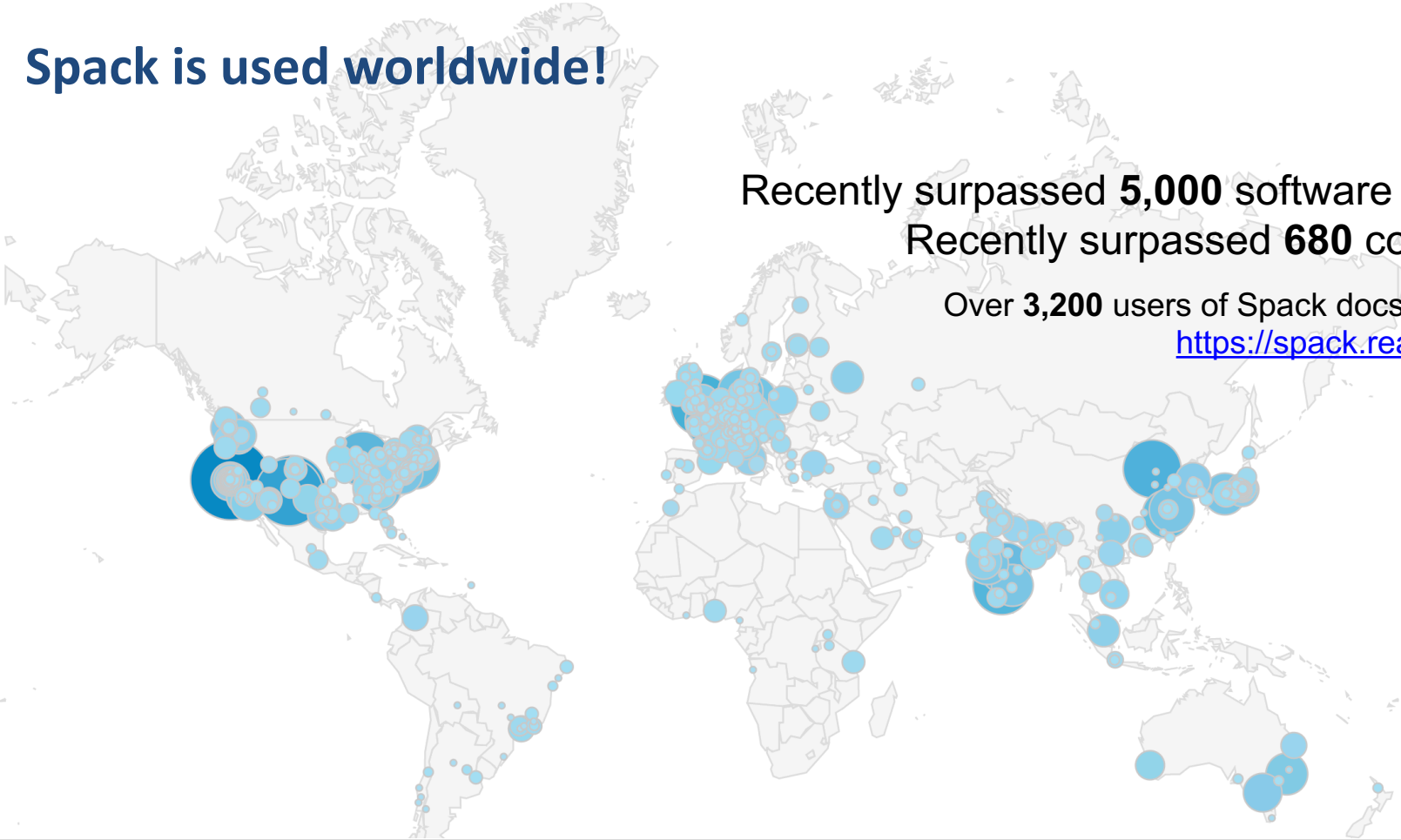
@spackpm

Who can use Spack?

People who want to use or distribute software for HPC!

1. **End Users of HPC Software**
   - Install and run HPC applications and tools
2. **HPC Application Teams**
   - Manage third-party dependency libraries
3. **Package Developers**
   - People who want to package their own software for distribution
4. **User support teams at HPC Centers**
   - People who deploy software for users at large HPC sites

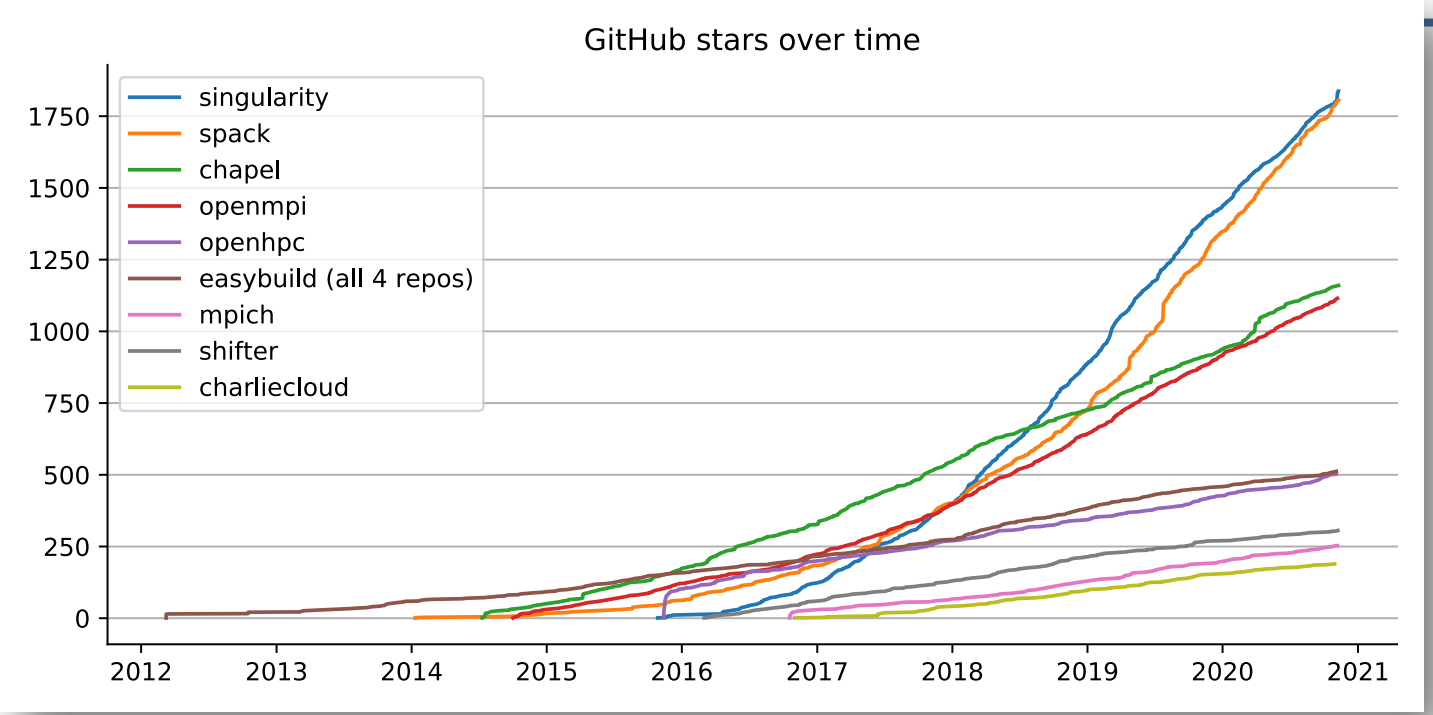
Spack is used worldwide!



Recently surpassed **5,000** software packages
Recently surpassed **680** contributors

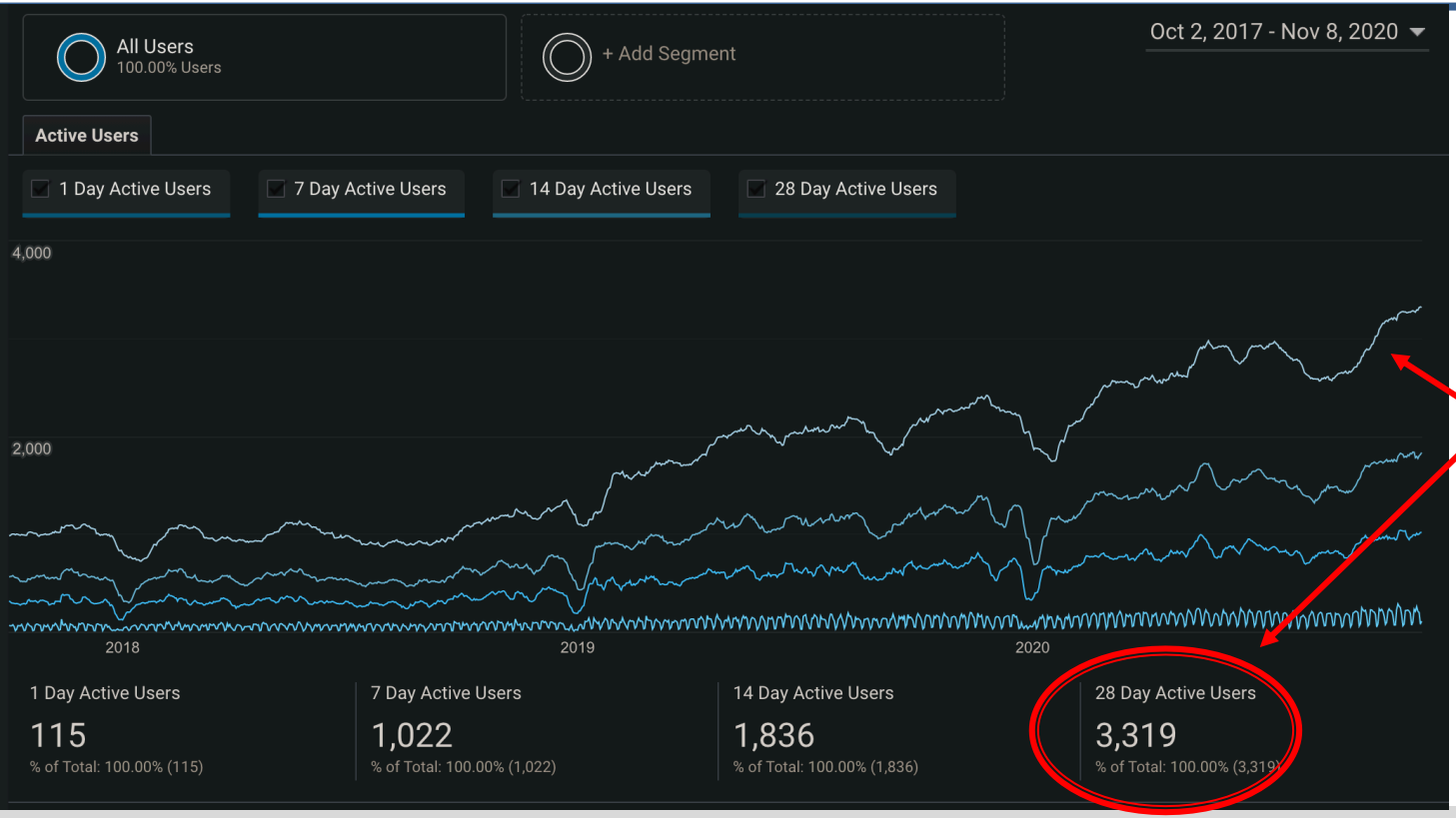
Over **3,200** users of Spack docs in Oct 2020
https://spack.readthedocs.io

Spack has been gaining adoption rapidly (if stars are an indicator)



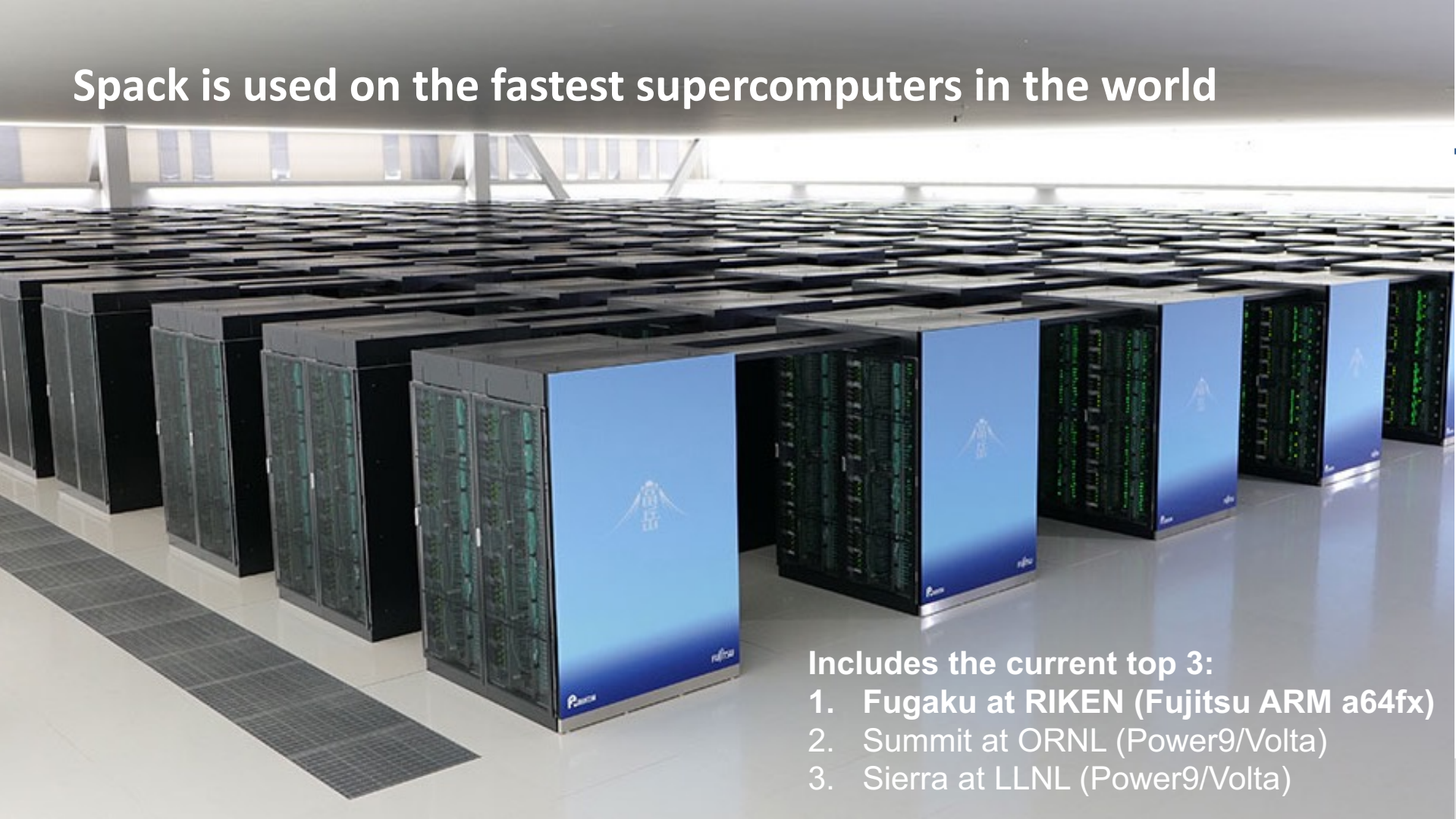
★ **Star Spack at github.com/spack/spack if you like the tutorial!**

Users on our documentation site have continued to increase



Broke 3,000 monthly active users for the first time.

Spack is used on the fastest supercomputers in the world



Includes the current top 3:

1. **Fugaku at RIKEN (Fujitsu ARM a64fx)**
2. Summit at ORNL (Power9/Volta)
3. Sierra at LLNL (Power9/Volta)

Spack is the deployment tool for the U.S. Exascale Computing Project

EXASCALE COMPUTING PROJECT

- Spack will be used to build software for the US's three upcoming exascale systems
- ECP has built the Extreme Scale Scientific Software Stack (E4S) with Spack – more at https://e4s.io
- We are helping ECP fulfill its mission – to create a tobust and capable exascale software ecosystem

https://e4s.io

One month of Spack development is pretty busy!

October 9, 2020 – November 9, 2020

Period: 1 month

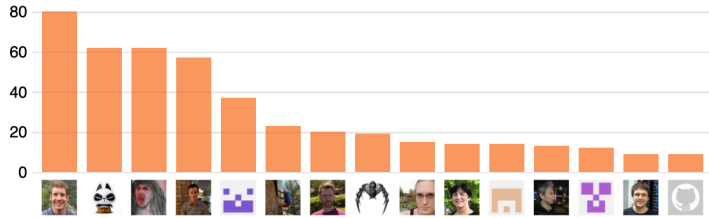
Overview

570 Active Pull Requests

176 Active Issues

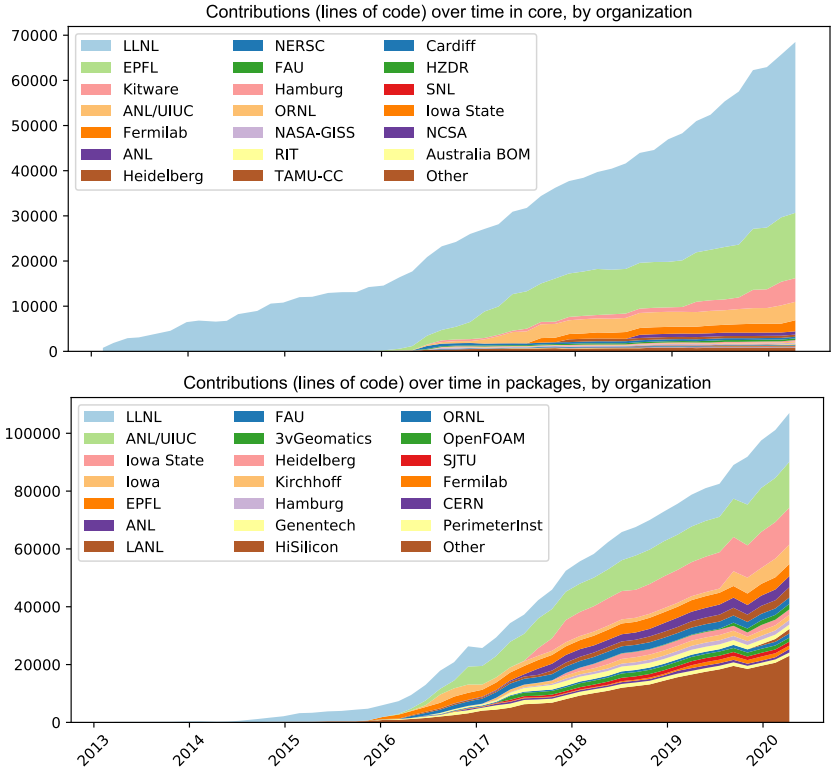
504 Merged Pull Requests	**66** Open Pull Requests	**102** Closed Issues	**74** New Issues

Excluding merges, **153 authors** have pushed **504 commits** to develop and **669 commits** to all branches. On develop, **774 files** have changed and there have been **25,151 additions** and **5,294 deletions**.



504 Pull requests merged by **132** people

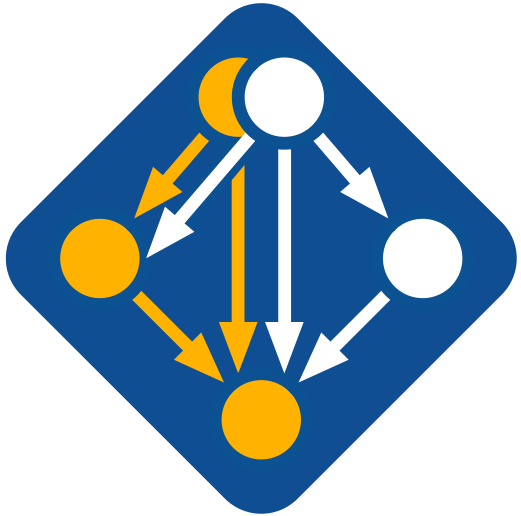
Contributions to Spack continue to grow!



- In November 2015, LLNL provided most of the contributions to Spack
- Since then, we've gone from 300 to over 5,000 packages
- Most packages are from external contributors!
- Many contributions in core, as well.
- We are committed to sustaining Spack's open source ecosystem!

Spack 0.15 was released at the end of June

- Many new features:
  - Packages can specify how they should be found on the system
    - `spack external find` command
  - Source code mirror for all Spack packages (from 0.15.1)
  - Testing builds in GitLab for all packages in E4S
  - Better Cray support
  - Better compiler optimization support on macOS
    - `apple-clang` now its own compiler
  - Enhancements and simplification to configuration
    - **`spack config add` / `spack config remove`**



- Over **4,300 packages**
  - 430 new since 0.14 in November 2019

- Several bugfix releases since (0.15.1, 0.15.2, 0.15.3, 0.15.4)

Spack is not the only tool that automates builds

1. **"Functional" Package Managers**
   - Nix — https://nixos.org/
   - GNU Guix — https://www.gnu.org/s/guix/

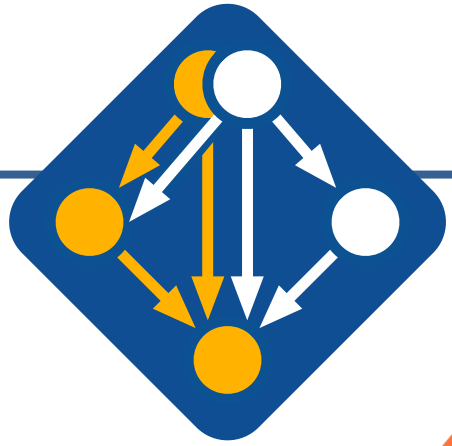
2. **Build-from-source Package Managers**
   - Homebrew, LinuxBrew — http://brew.sh
   - MacPorts — https://www.macports.org
   - Gentoo — https://gentoo.org

Other tools in the HPC Space:

- **Easybuild** — http://hpcugent.github.io/easybuild/
  - An installation tool for HPC
  - Focused on HPC system administrators – different package model from Spack
  - Relies on a fixed software stack – harder to tweak recipes for experimentation

- **Conda** — https://conda.io
  - Very popular binary package manager for data science
  - Not targeted at HPC; generally has unoptimized binaries

Join us at other events at SC!



- **CANOPIE-HPC workshop**
  - Thursday, Nov 12, 3:20-3:45pm
  - paper on archspec
    - spack's microarchitecture support library

- **Spack BOF**
  - Wednesday, Nov 18
  - 11:30am - 12:45pm EST
  - **Spack v0.16 to be announced**

SC20
Everywhere we are | more than hpc.

Spack Basics

Spack provides a *spec* syntax to describe customized DAG configurations

```
$ spack install mpileaks                          unconstrained
$ spack install mpileaks@3.3                      @ custom version
$ spack install mpileaks@3.3 %gcc@4.7.3           % custom compiler
$ spack install mpileaks@3.3 %gcc@4.7.3 +threads  +/- build option
$ spack install mpileaks@3.3 cppflags="-O3 -g3"   set compiler flags
$ spack install mpileaks@3.3 target=skylake       set target microarchitecture
$ spack install mpileaks@3.3 ^mpich@3.2 %gcc@4.9.3  ^ dependency information
```

- Each expression is a ***spec*** for a particular configuration
  - Each clause adds a constraint to the spec
  - Constraints are optional – specify only what you need.
  - Customize install on the command line!

- Spec syntax is recursive
  - Full control over the combinatorial build space

`spack list` shows what packages are available

```
$ spack list
==> 303 packages.
activeharmony   cgal             fish         gtkplus      libgd          mesa              openmpi          py-coverage       py-pycparser         qt          tcl
adept-utils     cgm              flex         harfbuzz     libgpg-error   metis             openspeedshop    py-cython         py-pyelftools        qthreads    texinfo
apex            cityhash         fltk         hdf          libjpeg-turbo  Mitos             openssl          py-dateutil       py-pygments          R           the_silver_searcher
arpack          cleverleaf       flux         hdf5         libjson-c      mpc               otf              py-epydoc         py-pylint            ravel       thrift
asciidoc        cloog            fontconfig   hwloc        libmng         mpe2              otf2             py-funcsigs       py-pypar             readline    tk
atk             cmake            freetype     hypre        libmonitor     mpfr              pango            py-genders        py-pyparsing         rose        tmux
atlas           cmocka           gasnet       icu          libNBC         mpibash           papi             py-gnuplot        py-pyqt              rsync       tmuxinator
atop            coreutils        gcc          icu4c        libpciaccess   mpich             paraver          py-h5py           py-pyside            ruby        trilinos
autoconf        cppcheck         gdb          ImageMagick  libpng         mpileaks          paraview         py-ipython        py-pytables          SAMRAI      uncrustify
automaded       cram             gdk-pixbuf   isl          libsodium      mrnet             parmetis         py-libxml2        py-python-daemon     samtools    util-linux
automake        cscope           geos         jdk          libtiff        mumps             parpack          py-lockfile       py-pytz              scalasca    valgrind
bear            cube             gflags       jemalloc     libtool        munge             patchelf         py-mako           py-rpy2              scorep      vim
bib2xhtml       curl             ghostscript  jpeg         libunwind      muster            pcre             py-matplotlib     py-scientificpython  scotch      vtk
binutils        czmq             git          judy         libuuid        mvapich2          pcre2            py-mock           py-scikit-learn      scr         wget
bison           damselfly        glib         julia        libxcb         nasm              pdt              py-mpi4py         py-scipy             silo        wx
boost           dbus             glm          launchmon    libxml2        ncdu              petsc            py-mx             py-setuptools        snappy      wxpropgrid
bowtie2         docbook-xml      global       lcms         libxshmfence   ncurses           pidx             py-mysqldb1       py-shiboken          sparsehash  xcb-proto
boxlib          doxygen          glog         leveldb      libxslt        netcdf            pixman           py-nose           py-sip               spindle     xerces-c
bzip2           dri2proto        glpk         libarchive   llvm           netgauge          pkg-config       py-numexpr        py-six               spot        xz
cairo           dtcmp            gmp          libcerf      llvm-lld       netlib-blas       pmgr_collective  py-numpy          py-sphinx            sqlite      yasm
callpath        dyninst          gmsh         libcircle    lmdb           netlib-lapack     postgresql       py-pandas         py-sympy             stat        zeromq
cblas           eigen            gnuplot      libdrm       lmod           netlib-scalapack  ppl              py-pbr            py-tappy             sundials    zlib
cbtf            elfutils         gnutls       libdwarf     lua            nettle            protobuf         py-periodictable  py-twisted           swig        zsh
cbtf-argonavis  elpa             gperf        libedit      lwgrp          ninja             py-astropy       py-pexpect        py-urwid             szip
cbtf-krell      expat            gperftools   libelf       lwm2           ompss             py-basemap       py-pil            py-virtualenv        tar
cbtf-lanl       extrae           graphlib     libevent     matio          ompt-openmp       py-biopython     py-pillow         py-yapf              task
cereal          exuberant-ctags  graphviz     libffi       mbedtls        opari2            py-blessings     py-pmw            python               taskd
cfitsio         fftw             gsl          libgcrypt    memaxes        openblas          py-cffi          py-pychecker      qhull                tau
```

- Spack has over 5,000 packages now.

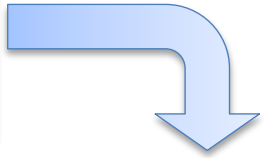
`spack find` shows what is installed

```
$ spack find
==> 103 installed packages.
-- linux-rhel6-x86_64 / gcc@4.4.7 ---------------------------------
ImageMagick@6.8.9-10  glib@2.42.1        libtiff@4.0.3     pango@1.36.8          qt@4.8.6
SAMRAI@3.9.1          graphlib@2.0.0     libtool@2.4.2     parmetis@4.0.3        qt@5.4.0
adept-utils@1.0       gtkplus@2.24.25    libxcb@1.11       pixman@0.32.6         ravel@1.0.0
atk@2.14.0            harfbuzz@0.9.37    libxml2@2.9.2     py-dateutil@2.4.0     readline@6.3
boost@1.55.0          hdf5@1.8.13        llvm@3.0          py-ipython@2.3.1      scotch@6.0.3
cairo@1.14.0          icu@54.1           metis@5.1.0       py-nose@1.3.4         starpu@1.1.4
callpath@1.0.2        jpeg@9a            mpich@3.0.4       py-numpy@1.9.1        stat@2.1.0
dyninst@8.1.2         libdwarf@20130729  ncurses@5.9       py-pytz@2014.10       xz@5.2.0
dyninst@8.1.2         libelf@0.8.13      ocr@2015-02-16    py-setuptools@11.3.1  zlib@1.2.8
fontconfig@2.11.1     libffi@3.1         openssl@1.0.1h    py-six@1.9.0
freetype@2.5.3        libmng@2.0.2       otf@1.12.5salmon  python@2.7.8
gdk-pixbuf@2.31.2     libpng@1.6.16      otf2@1.4          qhull@1.0

-- linux-rhel6-x86_64 / gcc@4.8.2 ---------------------------------
adept-utils@1.0.1  boost@1.55.0  cmake@5.6-special  libdwarf@20130729  mpich@3.0.4
adept-utils@1.0.1  cmake@5.6     dyninst@8.1.2      libelf@0.8.13      openmpi@1.8.2

-- linux-rhel6-x86_64 / intel@14.0.2 ------------------------------
hwloc@1.9  mpich@3.0.4  starpu@1.1.4

-- linux-rhel6-x86_64 / intel@15.0.0 ------------------------------
adept-utils@1.0.1  boost@1.55.0  libdwarf@20130729  libelf@0.8.13  mpich@3.0.4

-- linux-rhel6-x86_64 / intel@15.0.1 ------------------------------
adept-utils@1.0.1  callpath@1.0.2  libdwarf@20130729  mpich@3.0.4
boost@1.55.0       hwloc@1.9       libelf@0.8.13      starpu@1.1.4
```

- All the versions coexist!
  - Multiple versions of same package are ok.
- Packages are installed to automatically find correct dependencies.
- Binaries work *regardless of user's environment*.
- Spack also generates module files.
  - Don't *have* to use them.

Users can query the full dependency configuration of installed packages.

```
$ spack find callpath
==> 2 installed packages.
-- linux-rhel6-x86_64 / clang@3.4 --     -- linux-rhel6-x86_64 / gcc@4.9.2 -------
callpath@1.0.2                           callpath@1.0.2
```



Expand dependencies with `spack find -d`

```
$ spack find -dl callpath
==> 2 installed packages.
-- linux-rhel6-x86_64 / clang@3.4 -----      -- linux-rhel6-x86_64 / gcc@4.9.2 -----
xv2clz2    callpath@1.0.2                    udltshs    callpath@1.0.2
ckjazss        ^adept-utils@1.0.1            rfsu7fb        ^adept-utils@1.0.1
3ws43m4            ^boost@1.59.0             ybet64y            ^boost@1.55.0
ft7znm6            ^mpich@3.1.4              aa4ar6i            ^mpich@3.1.4
qqnuet3        ^dyninst@8.2.1                tmnnge5        ^dyninst@8.2.1
3ws43m4            ^boost@1.59.0             ybet64y            ^boost@1.55.0
g65rdud            ^libdwarf@20130729        g2mxrl2            ^libdwarf@20130729
cj5p5fk                ^libelf@0.8.13        ynpai3j                ^libelf@0.8.13
cj5p5fk            ^libelf@0.8.13            ynpai3j            ^libelf@0.8.13
g65rdud        ^libdwarf@20130729            g2mxrl2        ^libdwarf@20130729
cj5p5fk            ^libelf@0.8.13            ynpai3j            ^libelf@0.8.13
cj5p5fk        ^libelf@0.8.13                ynpai3j        ^libelf@0.8.13
ft7znm6        ^mpich@3.1.4                  aa4ar6i        ^mpich@3.1.4
```

- Architecture, compiler, versions, and variants may differ between builds.

Spack manages installed compilers

- Compilers are automatically detected
  - Automatic detection determined by OS
  - Linux: PATH
  - Cray: `module avail`
- Compilers can be manually added
  - Including Spack-built compilers

```
$ spack compilers
==> Available compilers
-- gcc ---------------------------------
gcc@4.2.1      gcc@4.9.3

-- clang -------------------------------
clang@6.0
```

compilers.yaml

```
compilers:
- compiler:
    modules: []
    operating_system: ubuntu14
    paths:
      cc: /usr/bin/gcc/4.9.3/gcc
      cxx: /usr/bin/gcc/4.9.3/g++
      f77: /usr/bin/gcc/4.9.3/gfortran
      fc: /usr/bin/gcc/4.9.3/gfortran
    spec: gcc@4.9.3
- compiler:
    modules: []
    operating_system: ubuntu14
    paths:
      cc: /usr/bin/clang/6.0/clang
      cxx: /usr/bin/clang/6.0/clang++
      f77: null
      fc: null
    spec: clang@6.0
- compiler:
    ...
```

Hands-on Time: Spack Basics

Follow script at spack-tutorial.readthedocs.io

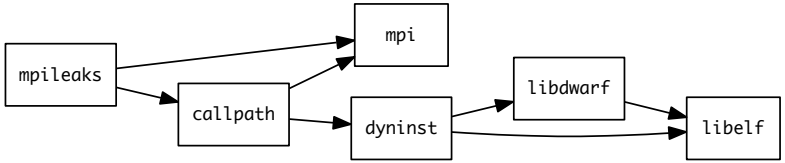
Core Spack Concepts

Most existing tools do not support combinatorial versioning

- Traditional binary package managers
  - RPM, yum, APT, yast, etc.
  - Designed to manage a single stack.
  - Install *one* version of each package in a single prefix (`/usr`).
  - Seamless upgrades to a *stable, well tested* stack
- Port systems
  - BSD Ports, portage, Macports, Homebrew, Gentoo, etc.
  - Minimal support for builds parameterized by compilers, dependency versions.
- Virtual Machines and Linux Containers (Docker)
  - Containers allow users to build environments for different applications.
  - Does not solve the build problem (someone has to build the image)
  - Performance, security, and upgrade issues prevent widespread HPC deployment.

Spack handles combinatorial software complexity

Dependency DAG



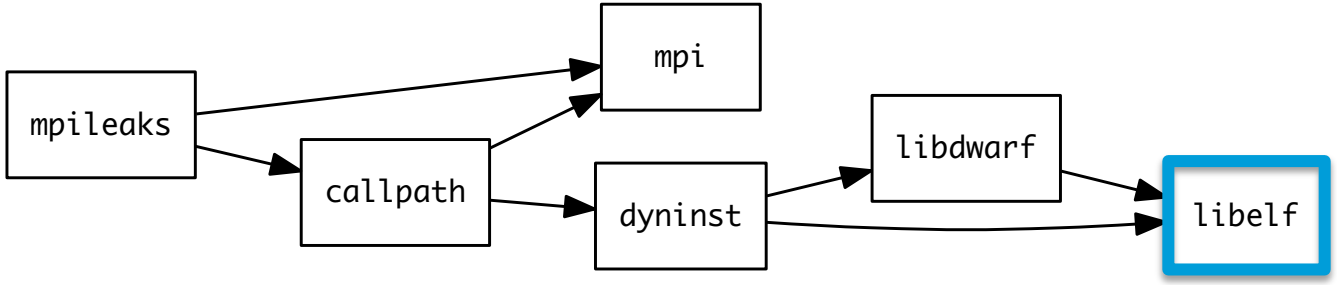
Installation Layout

Hash

```
opt
└── spack
    ├── darwin-mojave-skylake
    |   └── clang-10.0.0-apple
    |       ├── bzip2-1.0.8-hc4sm4vuzpm4znmvrfzri4ow2mkphe2e
    |       ├── python-3.7.6-daqqpssxb6qbfrztsezkmhus3xoflbsy
    |       ├── sqlite-3.30.1-u64v26igxvxyn23hysmklfums6tgjv5r
    |       ├── xz-5.2.4-u5eawkvaoc7vonabe6nndkcfwuv233cj
    |       └── zlib-1.2.11-x46q4wm46ay4pltriijbgizxjrhbaka6
    ├── darwin-mojave-x86_64
    |   └── clang-10.0.0-apple
    |       └── coreutils-8.29-pl2kcytejqcys5dzecfrtjqxfdssvnob
```

- Each unique dependency graph is a unique ***configuration***.
- Each configuration in a unique directory.
  - Multiple configurations of the same package can coexist.
- **Hash** of entire directed acyclic graph (DAG) is appended to each prefix.
- Installed packages automatically find dependencies
  - Spack embeds RPATHs in binaries.
  - No need to use modules or set LD_LIBRARY_PATH
  - Things work *the way you built them*

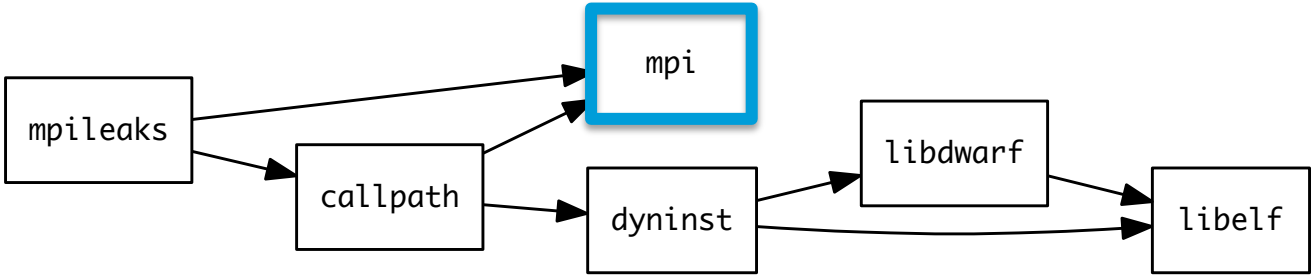
Spack Specs can constrain versions of dependencies




```
$ spack install mpileaks %intel@12.1 ^libelf@0.8.12
```

- Spack ensures *one* configuration of each library per DAG
  - Ensures ABI consistency.
  - User does not need to know DAG structure; only the dependency *names.*
- Spack can ensure that builds use the same compiler, or you can mix
  - Working on ensuring ABI compatibility when compilers are mixed.

Spack handles ABI-incompatible, versioned interfaces like MPI



- `mpi` is a *virtual dependency*
- Install the same package built with two different MPI implementations:

```
$ spack install mpileaks ^mvapich@1.9
```

```
$ spack install mpileaks ^openmpi@1.4:
```

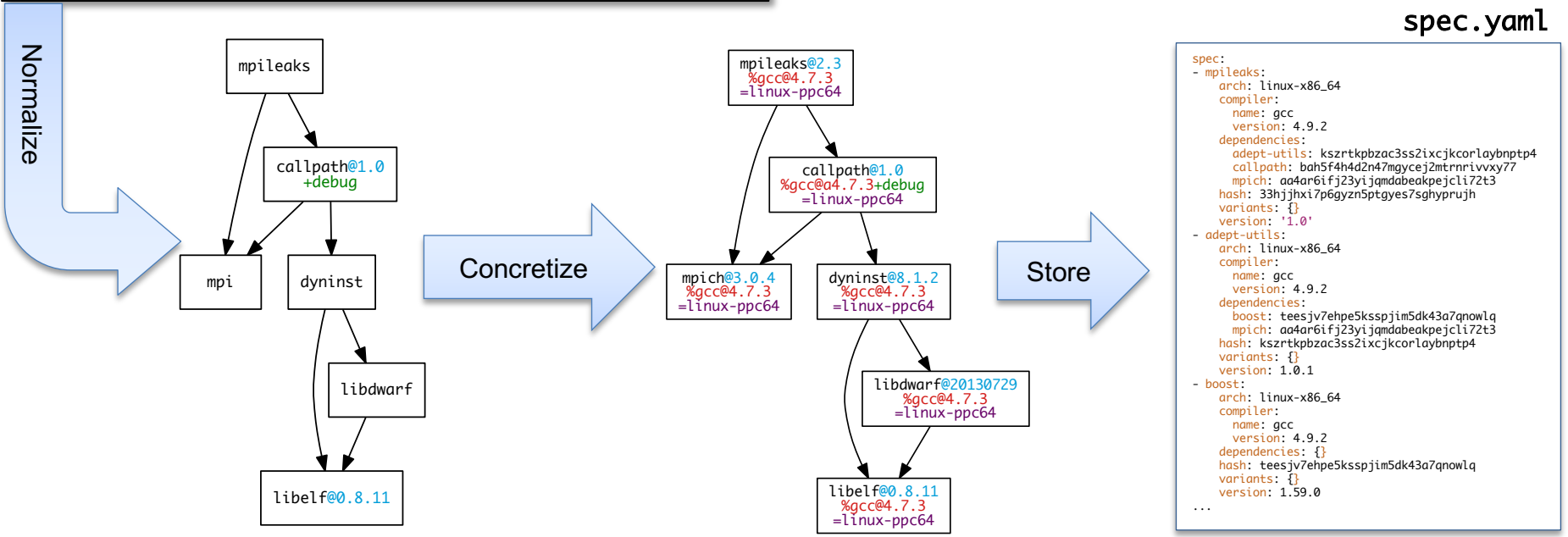
- Let Spack choose MPI implementation, as long as it provides MPI 2 interface:

```
$ spack install mpileaks ^mpi@2
```

Concretization fills in missing configuration details when the user is not explicit.

```
mpileaks ^callpath@1.0+debug ^libelf@0.8.11
```

User input: *abstract* spec with some constraints



spec.yaml

```
spec:
- mpileaks:
    arch: linux-x86_64
    compiler:
      name: gcc
      version: 4.9.2
    dependencies:
      adept-utils: kszrtkpbzac3ss2ixcjkcorlaybnptp4
      callpath: bah5f4h4d2n47mgycej2mtrnrivvxy77
      mpich: aa4ar6ifj23yijqmdabeakpejcli72t3
    hash: 33hjjhxi7p6gyzn5ptgyes7sghyprujh
    variants: {}
    version: '1.0'
- adept-utils:
    arch: linux-x86_64
    compiler:
      name: gcc
      version: 4.9.2
    dependencies:
      boost: teesjv7ehpe5ksspjim5dk43a7qnowlq
      mpich: aa4ar6ifj23yijqmdabeakpejcli72t3
    hash: kszrtkpbzac3ss2ixcjkcorlaybnptp4
    variants: {}
    version: 1.0.1
- boost:
    arch: linux-x86_64
    compiler:
      name: gcc
      version: 4.9.2
    dependencies: {}
    hash: teesjv7ehpe5ksspjim5dk43a7qnowlq
    variants: {}
    version: 1.59.0
...
```

Abstract, normalized spec with some dependencies.

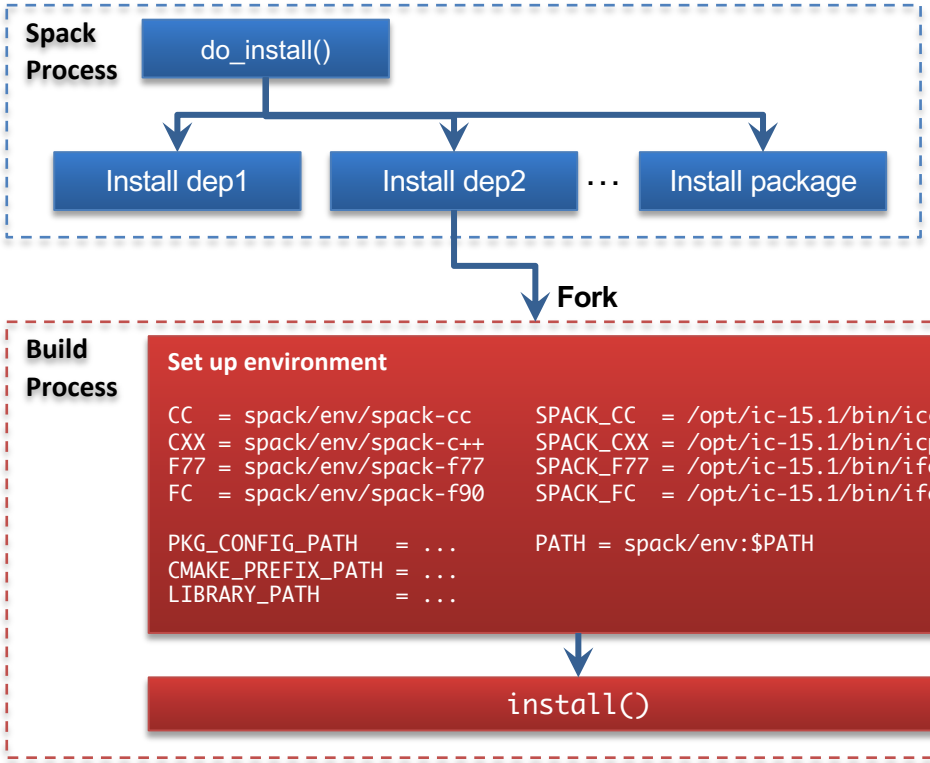
Concrete spec is fully constrained and can be passed to install.

Detailed provenance is stored with the installed package

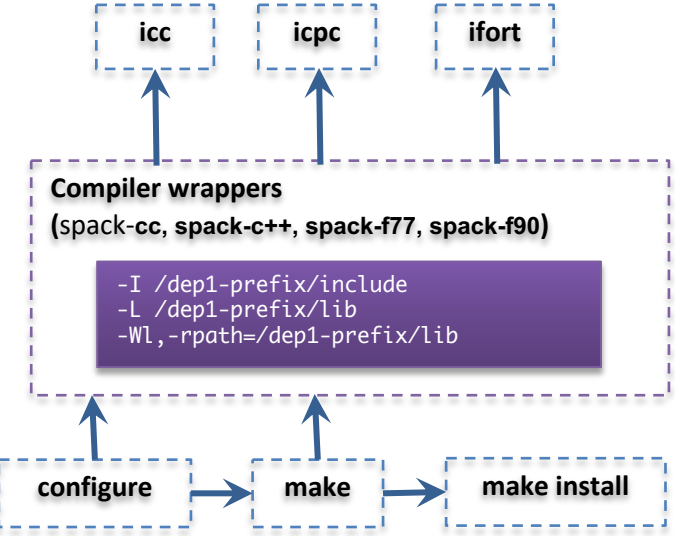
Use `spack spec` to see the results of concretization

```
$ spack spec mpileaks
Input spec
------------------------------
  mpileaks

Concretized
------------------------------
  mpileaks@1.0%gcc@5.3.0 arch=darwin-elcapitan-x86_64
      ^adept-utils@1.0.1%gcc@5.3.0 arch=darwin-elcapitan-x86_64
          ^boost@1.61.0%gcc@5.3.0+atomic+chrono+date_time~debug+filesystem~graph
           ~icu_support+iostreams+locale+log+math~mpi+multithreaded+program_options
           ~python+random +regex+serialization+shared+signals+singlethreaded+system
           +test+thread+timer+wave arch=darwin-elcapitan-x86_64
              ^bzip2@1.0.6%gcc@5.3.0 arch=darwin-elcapitan-x86_64
              ^zlib@1.2.8%gcc@5.3.0 arch=darwin-elcapitan-x86_64
          ^openmpi@2.0.0%gcc@5.3.0~mxm~pmi~psm~psm2~slurm~sqlite3~thread_multiple~tm~verbs+vt arch=darwin-elcapitan-x86_64
              ^hwloc@1.11.3%gcc@5.3.0 arch=darwin-elcapitan-x86_64
                  ^libpciaccess@0.13.4%gcc@5.3.0 arch=darwin-elcapitan-x86_64
                      ^libtool@2.4.6%gcc@5.3.0 arch=darwin-elcapitan-x86_64
                          ^m4@1.4.17%gcc@5.3.0+sigsegv arch=darwin-elcapitan-x86_64
                              ^libsigsegv@2.10%gcc@5.3.0 arch=darwin-elcapitan-x86_64
      ^callpath@1.0.2%gcc@5.3.0 arch=darwin-elcapitan-x86_64
          ^dyninst@9.2.0%gcc@5.3.0~stat_dysect arch=darwin-elcapitan-x86_64
              ^libdwarf@20160507%gcc@5.3.0 arch=darwin-elcapitan-x86_64
                  ^libelf@0.8.13%gcc@5.3.0 arch=darwin-elcapitan-x86_64
```

Spack builds each package in its own compilation environment



- **Forked build process isolates environment for each build.**
- **Uses compiler wrappers to:**
  - Add include, lib, and RPATH flags
  - Ensure that dependencies are found automatically
  - Load Cray modules (use right compiler/system deps)



Extensions and Python Support

- Spack installs each package in its own prefix
- Some packages need to be installed within directory structure of other packages
  - i.e., Python modules installed in $prefix/lib/python-<version>/site-packages
  - Spack supports this via extensions

```
class PyNumpy(Package):
    """NumPy is the fundamental package for scientific computing with Python."""

    homepage = "https://numpy.org"
    url      = "https://pypi.python.org/packages/source/n/numpy/numpy-1.9.1.tar.gz"
    version('1.9.1', ' 78842b73560ec378142665e712ae4ad9')

    extends('python')

    def install(self, spec, prefix):
        setup_py("install", "--prefix={0}".format(prefix))
```

Spack extensions

- Some packages need to be installed within directory structure of other packages
- Examples of extension packages:
  - python libraries are a good example
  - R, Lua, perl
  - Need to maintain combinatorial versioning

```
$ spack activate py-numpy @1.10.4
```

- Symbolic link to Spack install location
- Automatically activate for correct version of dependency
  - Provenance information from DAG
  - Activate all dependencies that are extensions as well

```
spack/opt/
  linux-rhel6-x86_64/
    gcc-4.7.2/
      python-2.7.12-6y6vvaw/
        lib/python2.7/site-packages/
          ..
      py-numpy-1.10.4-oaxix36/
        lib/python2.7/site-packages/
          numpy/
...
```

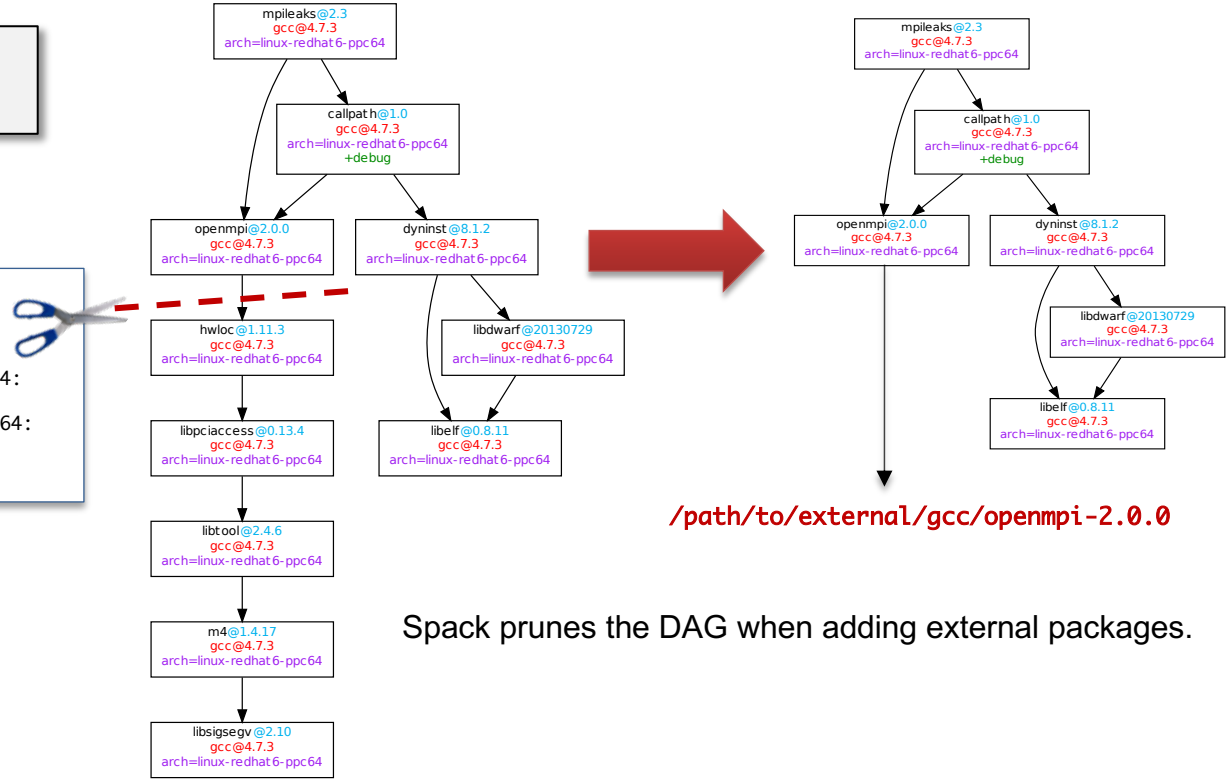
```
spack/opt/
  linux-rhel6-x86_64/
    gcc-4.7.2/
      python-2.7.12-6y6vvaw/
        lib/python2.7/site-packages/
          numpy@
      py-numpy-1.10.4-oaxix36/
        lib/python2.7/site-packages/
          numpy/
...
```

Building against externally installed software

```
mpileaks ^callpath@1.0+debug
    ^openmpi ^libelf@0.8.11
```

packages.yaml

```
packages:
  mpi:
    buildable: False
    paths:
      openmpi@2.0.0 %gcc@4.7.3 arch=linux-rhel6-ppc64:
        /path/to/external/gcc/openmpi-2.0.0
      openmpi@1.10.3 %gcc@4.7.3 arch=linux-rhel6-ppc64:
        /path/to/external/gcc/openmpi-1.10.3
      ...
```



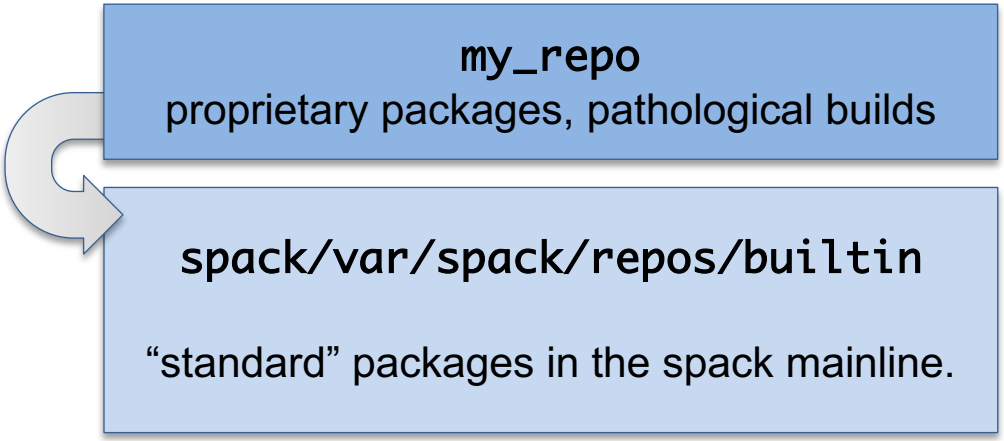
Users register external packages in a configuration file (more on these later).

Spack prunes the DAG when adding external packages.

Spack package repositories

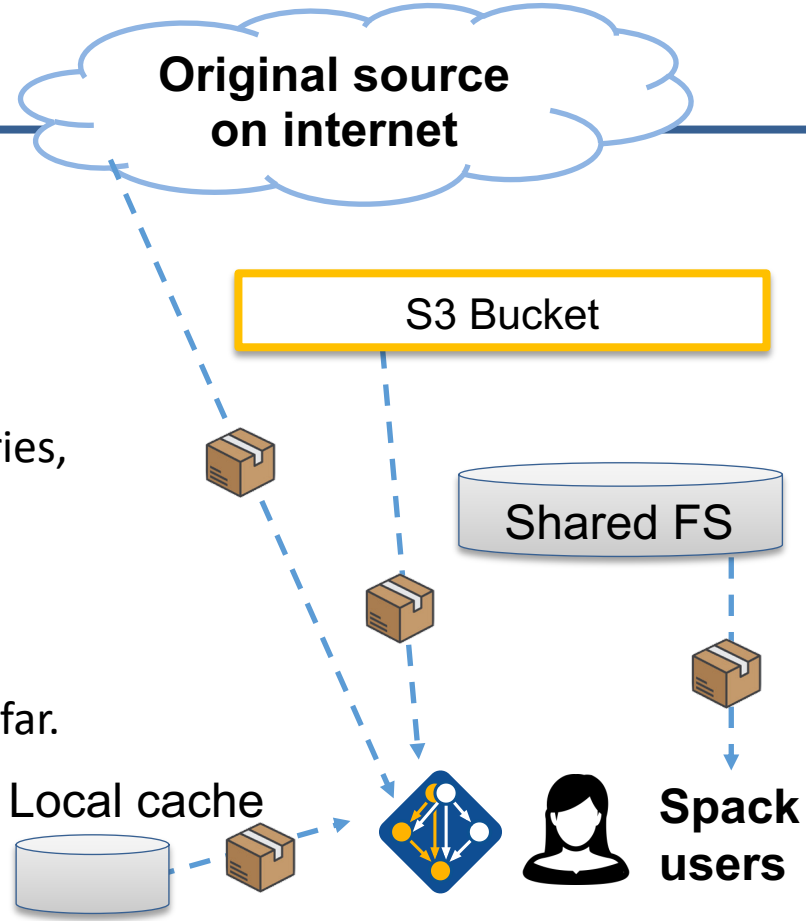
- Spack supports external package repositories
  - Separate directories of package recipes
- Many reasons to use this:
  - Some packages can't be released publicly
  - Some sites require ~~bizarre~~ custom builds
  - Override default packages with site-specific versions
- Packages are composable:
  - External repositories can be layered on top of the built-in packages
  - Custom packages can depend on built-in packages (or packages in other repos)

```
$ spack repo create /path/to/my_repo
$ spack repo add my_repo
$ spack repo list
==> 2 package repositories.
my_repo    /path/to/my_repo
builtin    spack/var/spack/repos/builtin
```



Spack mirrors

- Spack allows you to define *mirrors:*
  - Directories in the filesystem
  - On a web server
  - In an S3 bucket
- Mirrors are archives of fetched tarballs, repositories, and other resources needed to build
  - Can also contain binary packages
- By default, Spack maintains a mirror in var/spack/cache of everything you've fetched so far.
- You can host mirrors internal to your site
  - See the documentation for more details



Hands-on Time: Configuration

Follow script at spack-tutorial.readthedocs.io

Making your own Spack Packages

Hands-on Time: Creating Packages

Follow script at spack-tutorial.readthedocs.io

Day 2
Spack Review

Spack provides a *spec* syntax to describe customized DAG configurations

```
$ spack install mpileaks                          unconstrained
$ spack install mpileaks@3.3                      @ custom version
$ spack install mpileaks@3.3 %gcc@4.7.3           % custom compiler
$ spack install mpileaks@3.3 %gcc@4.7.3 +threads  +/- build option
$ spack install mpileaks@3.3 cppflags="-O3 -g3"   set compiler flags
$ spack install mpileaks@3.3 target=skylake       set target microarchitecture
$ spack install mpileaks@3.3 ^mpich@3.2 %gcc@4.9.3  ^ dependency information
```

- Each expression is a ***spec*** for a particular configuration
  - Each clause adds a constraint to the spec
  - Constraints are optional – specify only what you need.
  - Customize install on the command line!

- Spec syntax is recursive
  - Full control over the combinatorial build space

Spack packages are *templates*
They use a simple Python DSL to define how to build

Not shown: patches, resources, conflicts, other directives.

```
from spack import *

class Kripke(CMakePackage):
    """Kripke is a simple, scalable, 3D Sn deterministic particle
       transport proxy/mini app.
    """

    homepage = "https://computation.llnl.gov/projects/co-design/kripke"
    url      = "https://computation.llnl.gov/projects/co-design/download/kripke-openmp-1.1.tar.gz"

    version('1.2.3', sha256='3f7f2eef0d1ba5825780d626741eb0b3f026a096048d7ec4794d2a7dfbe2b8a6')
    version('1.2.2', sha256='eaf9ddf562416974157b34d00c3a1c880fc5296fce2aa2efa039a86e0976f3a3')
    version('1.1', sha256='232d74072fc7b848fa2adc8a1bc839ae8fb5f96d50224186601f55554a25f64a')

    variant('mpi',    default=True, description='Build with MPI.')
    variant('openmp', default=True, description='Build with OpenMP enabled.')

    depends_on('mpi', when='+mpi')
    depends_on('cmake@3.0:', type='build')

    def cmake_args(self):
        return [
            '-DENABLE_OPENMP=%s' % ('+openmp' in self.spec),
            '-DENABLE_MPI=%s' % ('+mpi' in self.spec),
        ]

    def install(self, spec, prefix):
        # Kripke does not provide install target, so we have to copy
        # things into place.
        mkdirp(prefix.bin)
        install('../spack-build/kripke', prefix.bin)
```

Base package
(CMake support)

Metadata at the class level

Versions

Variants (build options)

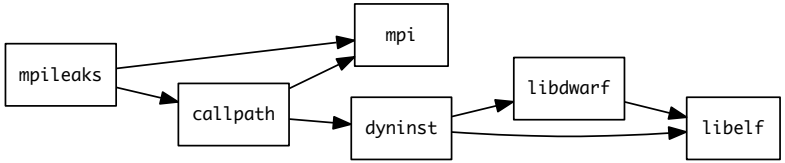
Dependencies
(note: same spec syntax)

Install logic
in instance methods

Don't typically need `install()` for `CMakePackage`, but we can work around codes that don't have it.

Spack handles combinatorial software complexity

Dependency DAG



Installation Layout

Hash

```
opt
└── spack
    ├── darwin-mojave-skylake
    |   └── clang-10.0.0-apple
    |       ├── bzip2-1.0.8-hc4sm4vuzpm4znmvrfzri4ow2mkphe2e
    |       ├── python-3.7.6-daqqpssxb6qbfrztsezkmhus3xoflbsy
    |       ├── sqlite-3.30.1-u64v26igxvxyn23hysmklfums6tgjv5r
    |       ├── xz-5.2.4-u5eawkvaoc7vonabe6nndkcfwuv233cj
    |       └── zlib-1.2.11-x46q4wm46ay4pltriijbgizxjrhbaka6
    ├── darwin-mojave-x86_64
    |   └── clang-10.0.0-apple
    |       └── coreutils-8.29-pl2kcytejqcys5dzecfrtjqxfdssvnob
```

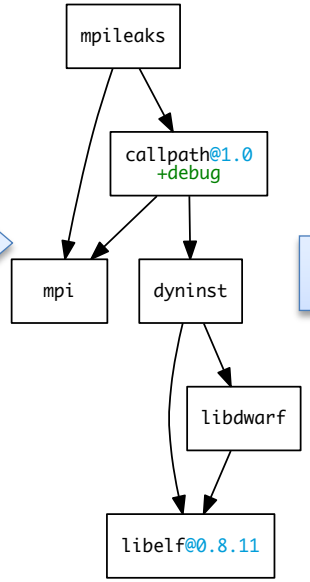
- Each unique dependency graph is a unique ***configuration***.
- Each configuration in a unique directory.
  - Multiple configurations of the same package can coexist.
- **Hash** of entire directed acyclic graph (DAG) is appended to each prefix.
- Installed packages automatically find dependencies
  - Spack embeds RPATHs in binaries.
  - No need to use modules or set LD_LIBRARY_PATH
  - Things work *the way you built them*

Concretization fills in missing configuration details when the user is not explicit.

```
mpileaks ^callpath@1.0+debug ^libelf@0.8.11
```

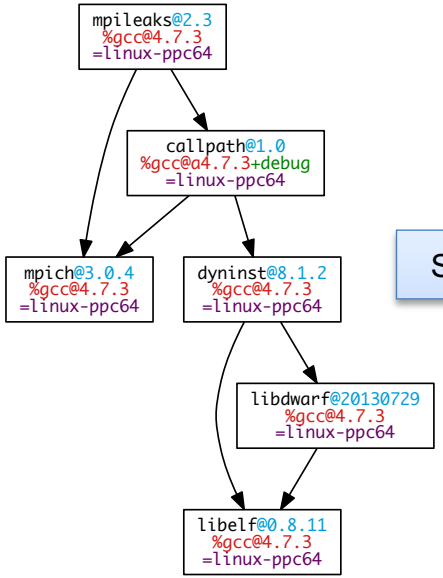
User input: *abstract* spec with some constraints

Normalize



Abstract, normalized spec with some dependencies.

Concretize



Concrete spec is fully constrained and can be passed to install.

Store

spec.yaml

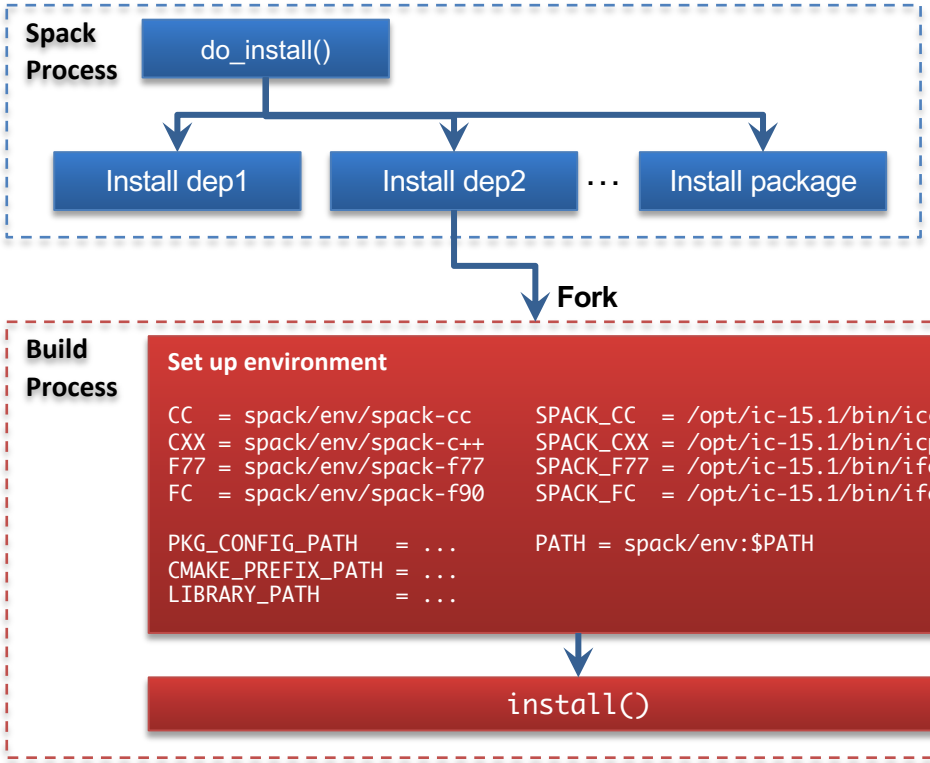
```
spec:
- mpileaks:
    arch: linux-x86_64
    compiler:
      name: gcc
      version: 4.9.2
    dependencies:
      adept-utils: kszrtkpbzac3ss2ixcjkcorlaybnptp4
      callpath: bah5f4h4d2n47mgycej2mtrnrivvxy77
      mpich: aa4ar6ifj23yijqmdabeakpejcli72t3
    hash: 33hjjhxi7p6gyzn5ptgyes7sghyprujh
    variants: {}
    version: '1.0'
- adept-utils:
    arch: linux-x86_64
    compiler:
      name: gcc
      version: 4.9.2
    dependencies:
      boost: teesjv7ehpe5ksspjim5dk43a7qnowlq
      mpich: aa4ar6ifj23yijqmdabeakpejcli72t3
    hash: kszrtkpbzac3ss2ixcjkcorlaybnptp4
    variants: {}
    version: 1.0.1
- boost:
    arch: linux-x86_64
    compiler:
      name: gcc
      version: 4.9.2
    dependencies: {}
    hash: teesjv7ehpe5ksspjim5dk43a7qnowlq
    variants: {}
    version: 1.59.0
...
```

Detailed provenance is stored with the installed package

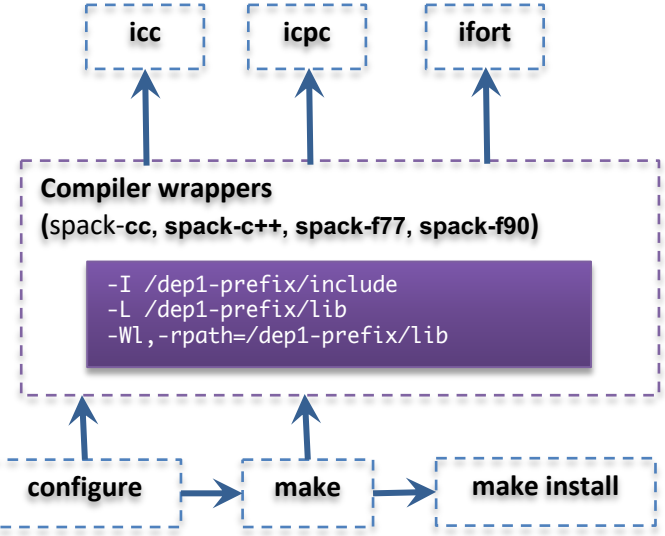
Use `spack spec` to see the results of concretization

```
$ spack spec mpileaks
Input spec
------------------------------
  mpileaks

Concretized
------------------------------
  mpileaks@1.0%gcc@5.3.0 arch=darwin-elcapitan-x86_64
      ^adept-utils@1.0.1%gcc@5.3.0 arch=darwin-elcapitan-x86_64
          ^boost@1.61.0%gcc@5.3.0+atomic+chrono+date_time~debug+filesystem~graph
           ~icu_support+iostreams+locale+log+math~mpi+multithreaded+program_options
           ~python+random +regex+serialization+shared+signals+singlethreaded+system
           +test+thread+timer+wave arch=darwin-elcapitan-x86_64
              ^bzip2@1.0.6%gcc@5.3.0 arch=darwin-elcapitan-x86_64
              ^zlib@1.2.8%gcc@5.3.0 arch=darwin-elcapitan-x86_64
          ^openmpi@2.0.0%gcc@5.3.0~mxm~pmi~psm~psm2~slurm~sqlite3~thread_multiple~tm~verbs+vt arch=darwin-elcapitan-x86_64
              ^hwloc@1.11.3%gcc@5.3.0 arch=darwin-elcapitan-x86_64
                  ^libpciaccess@0.13.4%gcc@5.3.0 arch=darwin-elcapitan-x86_64
                      ^libtool@2.4.6%gcc@5.3.0 arch=darwin-elcapitan-x86_64
                          ^m4@1.4.17%gcc@5.3.0+sigsegv arch=darwin-elcapitan-x86_64
                              ^libsigsegv@2.10%gcc@5.3.0 arch=darwin-elcapitan-x86_64
      ^callpath@1.0.2%gcc@5.3.0 arch=darwin-elcapitan-x86_64
          ^dyninst@9.2.0%gcc@5.3.0~stat_dysect arch=darwin-elcapitan-x86_64
              ^libdwarf@20160507%gcc@5.3.0 arch=darwin-elcapitan-x86_64
                  ^libelf@0.8.13%gcc@5.3.0 arch=darwin-elcapitan-x86_64
```

Spack builds each package in its own compilation environment



- **Forked build process isolates environment for each build.**
- **Uses compiler wrappers to:**
  - Add include, lib, and RPATH flags
  - Ensure that dependencies are found automatically
  - Load Cray modules (use right compiler/system deps)



Environments,
`spack.yaml` and `spack.lock`

Follow script at **spack-tutorial.readthedocs.io**

Spack Stacks

Follow script at spack-tutorial.readthedocs.io

Hands-on Time: Environment Modules

Follow script at **spack-tutorial.readthedocs.io**

Developer Workflows

Follow script at spack-tutorial.readthedocs.io

Scripting and spack-python

Follow script at spack-tutorial.readthedocs.io

More New Features and the Road Ahead

Spack understands specific target microarchitectures

- We have developed a cross-platform library to detect and compare microarchitecture metadata
  - Detects based on /proc/cpuinfo (Linux), sysctl (Mac)
  - Allows comparisons for compatibility, e.g.:

```
skylake > broadwell
zen2 > x86_64
```

- Key features:
  - Know which compilers support which chips/which flags
  - Determine compatibility
  - Enable creation and reuse of optimized binary packages
  - Easily query available architecture features for portable build recipes

- We will be extracting this as a standalone library for other tools & languages
  - Hope to make this standard!

```
$ spack arch --known-targets
Generic architectures (families)
    aarch64  ppc64  ppc64le  x86  x86_64

IBM - ppc64
    power7  power8  power9

IBM - ppc64le
    power8le  power9le

AuthenticAMD - x86_64
    barcelona  bulldozer  piledriver  steamroller  excavator  zen  zen2

GenuineIntel - x86_64
    nocona   westmere     haswell    mic_knl         cascadelake
    core2    sandybridge  broadwell  skylake_avx512  icelake
    nehalem  ivybridge    skylake    cannonlake

GenuineIntel - x86
    i686  pentium2  pentium3  pentium4  prescott
```

Extensive microarchitecture knowledge

```
class OpenBlas(Package):

    def configure_args(self, spec):
        args = []
        if 'avx512' in spec.target:
            args.append('--with-avx512')
        ...
        return args
```

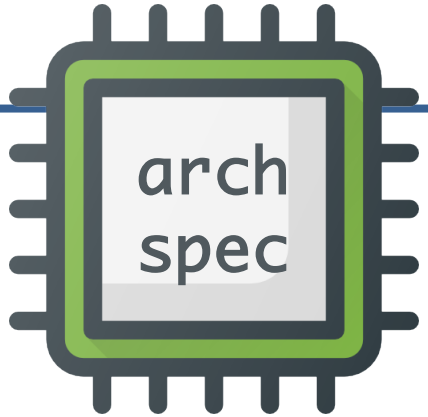
Simple feature query

```
$ spack install lbann target=cascadelake

$ spack install petsc target=zen2
```

Specialized installations

Check out Archspec!

- Standalone library, extracted from Spack
- Use fine-grained, human-readable labels, e.g.:
  - broadwell, haswell, skylake
  - instead of x86_64, aarch64, ppc64 etc.
- Query capabilities and more
  - “Does haswell support AVX-512?” “no.”
  - “How do I compile for broadwell with icc?”



github.com/archspec

ReadTheDocs: archspec.rtfd.io

License: Apache 2.0 OR MIT

```
pip3 install archspec
```

archspec will be presented Thursday at the CANOPIE-HPC workshop!

Generate container images from environments (0.14)

```
spack:
  specs:
  - gromacs+mpi
  - mpich

  container:
    # Select the format of the recip
    # singularity or anything else t
    format: docker

    # Select from a valid list of im
    base:
      image: "centos:7"
      spack: develop

    # Whether or not to strip binari
    strip: true

    # Additional system packages tha
    os_packages:
    - libgomp

    # Extra instructions
    extra_instructions:
      final: |
RUN echo 'export PS1="\[$(tput bold)

    # Labels for the image
    labels:
      app: "gromacs"
      mpi: "mpich"
```

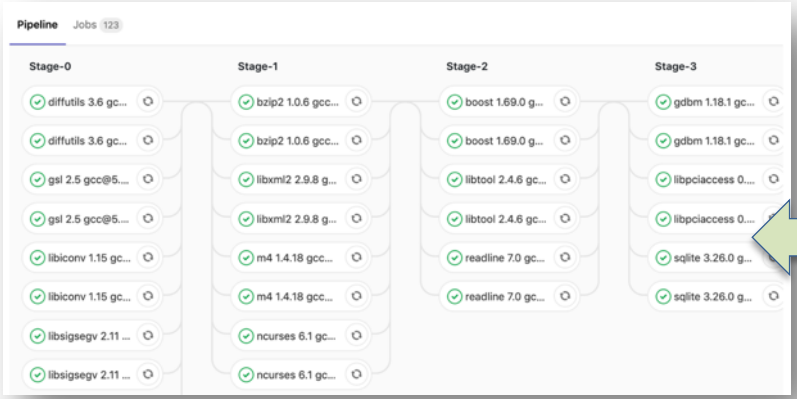
```
# Build stage with Spack pre-installed and ready to be used
FROM spack/centos7:latest as builder

# What we want to install and how we want to install it
# is specified in a manifest file (spack.yaml)
RUN mkdir /opt/spack-environment \
&&  (echo "spack:" \
&&   echo "  specs:" \
&&   echo "  - gromacs+mpi" \
&&   echo "  - mpich" \
&&   echo "  concretization: together" \
&&   echo "  config:" \
&&   echo "    install_tree: /opt/software" \
&&   echo "  view: /opt/view") > /opt/spack-environment/spack.yaml

# Install the software, remove unecessary deps
RUN cd /opt/spack-environment && spack install && spack gc -y

# Strip all the binaries
RUN find -L /opt/view/* -type f -exec readlink -f '{}' \; | \
    xargs file -i | \
    grep 'charset=binary' | \
    grep 'x-executable\|x-archive\|x-sharedlib' | \
    awk -F: '{print $1}' | xargs strip -s

# Modifications to the environment that are necessary to run
RUN cd /opt/spack-environment && \
    spack env activate --sh -d . >> /etc/profile.d/z10_spack_environment.sh


# Bare OS image to run the installed executables
FROM centos:7

COPY --from=builder /opt/spack-environment /opt/spack-environment
COPY --from=builder /opt/software /opt/software
COPY --from=builder /opt/view /opt/view
C  --from=builder /etc/profile.d/z10_spack_environment.sh /etc/profile.d/z10_spack_en

m update -y && yum install -y epel-release && yum update -y
  install -y libgomp \
m -rf /var/cache/yum  && yum clean all

RUN echo 'export PS1="\[$(tput bold)\]\[$(tput setaf 1)\][gromacs]\[$(tput setaf 2)\]\u\[$(tput
```

- Any Spack environment can be bundled into a container image
  - Optional container section allows finer-grained customization
- Generated Dockerfile uses multi-stage builds to minimize size of final image
  - Strips binaries
  - Removes unneeded build deps with `spack gc`
- Can also generate Singularity recipes

`spack containerize`

Spack can generate CI Pipelines from environments

- User adds a `gitlab-ci` section to environment
  - Spack maps builds to GitLab runners
  - Generate gitlab-ci.yml with `spack ci` command
- Can run in a Kube cluster or on bare metal at an HPC site
  - Sends progress to CDash



`spack ci`

```
spack:
  definitions:
  - pkgs:
    - readline@7.0
  - compilers:
    - '%gcc@5.5.0'
  - oses:
    - os=ubuntu18.04
    - os=centos7
  specs:
  - matrix:
    - [$pkgs]
    - [$compilers]
    - [$oses]
  mirrors:
    cloud_gitlab: https://mirror.spack.io
  gitlab-ci:
    mappings:
      - spack-cloud-ubuntu:
        match:
          - os=ubuntu18.04
        runner-attributes:
          tags:
            - spack-k8s
          image: spack/spack_builder_ubuntu_18.04
      - spack-cloud-centos:
        match:
          - os=centos7
        runner-attributes:
          tags:
            - spack-k8s
          image: spack/spack_builder_centos_7
  cdash:
    build-group: Release Testing
    url: https://cdash.spack.io
    project: Spack
    site: Spack AWS Gitlab Instance
```

spack external find

```python
class Cmake(Package):
    executables = ['cmake']

    @classmethod
    def determine_spec_details(cls, prefix, exes_in_prefix):
        exe_to_path = dict(
            (os.path.basename(p), p) for p in exes_in_prefix
        )
        if 'cmake' not in exe_to_path:
            return None

        cmake = spack.util.executable.Executable(exe_to_path['cmake'])
        output = cmake('--version', output=str)
        if output:
            match = re.search(r'cmake.*version\s+(\S+)', output)
            if match:
                version_str = match.group(1)
                return Spec('cmake@{0}'.format(version_str))
```

Logic for finding external installations in `package.py`

```yaml
packages:
    cmake:
        paths:
          cmake@3.15.1: /usr/local
```

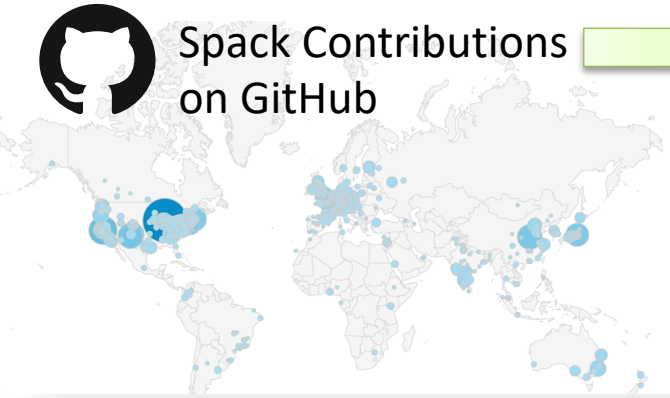
`packages.yaml` configuration

- Spack has has compiler detection for a while
  - Finds compilers in your PATH
  - Registers them for use
- We can find any package now
  - Package defines:
    - possible command names
    - how to query the command
  - Spack searches for known commands and adds them to configuration
- Community can easily enable tools to be set up rapidly

Spack 0.15.1 introduced a source code mirror for all packages

- Spack has long been vulnerable to unreliably hosted code
  - Outages at large sites like Sourceforge or GNU would leave Spack essentially down too.
  - Outages have been known to persist for long periods of time (GNU).
- Spack now has a dedicated S3 bucket with *all* sources, patches, and other resources needed to build
  - This is the first place we'll download things now
- **If other sites go down, Spack is still in business.**

We are testing our development branch and our release branches with ECP's E4S software stack

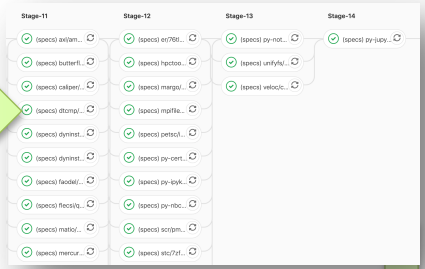


Spack Contributions on GitHub

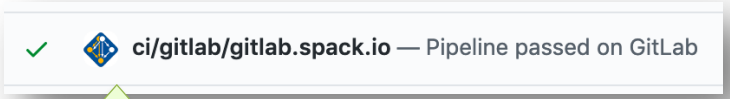
gitlab.spack.io

E4S spack.yaml configuration

spack ci



GitLab CI builds (changed) packages
- On every pull request
- On every release branch



- E4S is about 250 packages – will eventually include all ECP software products
  - We've started with E4S built for CentOS6, CentOS7, Ubuntu18
  - Will start expanding to include more packages from Spack, ECP facility platforms, more instances
- More on E4S at https://e4s.io

Spack v0.16 roadmap: `spack test` allows tests to be written directly in Spack packages

```
class Libsigsegv(AutotoolsPackage, GNUMirrorPackage):
    """GNU libsigsegv is a library for handling page faults in user mode."""

    # ... spack package contents ...

    extra_install_tests = 'tests/.libs'

    def test(self):
        data_dir = self.test_suite.current_test_data_dir
        smoke_test_c = data_dir.join('smoke_test.c')

        self.run_test(
            'cc', [
                '-I%s' % self.prefix.include,
                '-L%s' % self.prefix.lib, '-lsigsegv',
                smoke_test_c,
                '-o', 'smoke_test'
            ]
            purpose='check linking')

        self.run_test(
            'smoke_test', [], data_dir.join('smoke_test.out'),
            purpose='run built smoke test')

        self.run_test('sigsegv1': ['Test passed'], purpose='check sigsegv1 output')
        self.run_test('sigsegv2': ['Test passed'], purpose='check sigsegv2 output')
```

Tests are part of a regular Spack recipe class

Save source code from the build

User just defines a `test()` method

Retrieve saved source.
Link a simple executable.

Spack ensures that `cc` is a compatible compiler

Run the built smoke test and verify output

Run programs installed with package

Spack v0.16 roadmap: experimental new concretizer

- Used Clingo, the Potassco grounder/solver package
- ASP program has 2 parts:
  1. Large list of facts generated from our package repositories
     - 6,000 – 9,000 facts is typical – includes dependencies, options, etc.
  2. Small logic program (~130 lines)
- New algorithm (at least our part) is conceptually simpler:
  - Generate facts for all possible dependencies
  - Send facts and our logic program to the solver
  - Build a DAG from the results
- New concretizer can so far solve many situations that current concretizer can't
  - Backtracking is a win
  - Still requires an external solver
  - We'll make it experimental until 0.17.0, when we will figure out how best to automatically include an ASP or SMT solver

```
%-----------------------------------------------------------------------------
% Package: ucx
%-----------------------------------------------------------------------------
version_declared("ucx", "1.6.1", 0).
version_declared("ucx", "1.6.0", 1).
version_declared("ucx", "1.5.2", 2).
version_declared("ucx", "1.5.1", 3).
version_declared("ucx", "1.5.0", 4).
version_declared("ucx", "1.4.0", 5).
version_declared("ucx", "1.3.1", 6).
version_declared("ucx", "1.3.0", 7).
version_declared("ucx", "1.2.2", 8).
version_declared("ucx", "1.2.1", 9).
version_declared("ucx", "1.2.0", 10).

variant("ucx", "thread_multiple").
variant_single_value("ucx", "thread_multiple").
variant_default_value("ucx", "thread_multiple", "False").
variant_possible_value("ucx", "thread_multiple", "False").
variant_possible_value("ucx", "thread_multiple", "True").

declared_dependency("ucx", "numactl", "build").
declared_dependency("ucx", "numactl", "link").
node("numactl") :- depends_on("ucx", "numactl"), node("ucx").

declared_dependency("ucx", "rdma-core", "build").
declared_dependency("ucx", "rdma-core", "link").
node("rdma-core") :- depends_on("ucx", "rdma-core"), node("ucx").


%-----------------------------------------------------------------------------
% Package: util-linux
%-----------------------------------------------------------------------------
version_declared("util-linux", "2.29.2", 0).
version_declared("util-linux", "2.29.1", 1).
version_declared("util-linux", "2.25", 2).

variant("util-linux", "libuuid").
variant_single_value("util-linux", "libuuid").
variant_default_value("util-linux", "libuuid", "True").
variant_possible_value("util-linux", "libuuid", "False").
variant_possible_value("util-linux", "libuuid", "True").

declared_dependency("util-linux", "pkgconfig", "build").
declared_dependency("util-linux", "pkgconfig", "link").
node("pkgconfig") :- depends_on("util-linux", "pkgconfig"), node("util-linux").

declared_dependency("util-linux", "python", "build").
declared_dependency("util-linux", "python", "link").
node("python") :- depends_on("util-linux", "python"), node("util-linux").
```

Some facts for HDF5 package

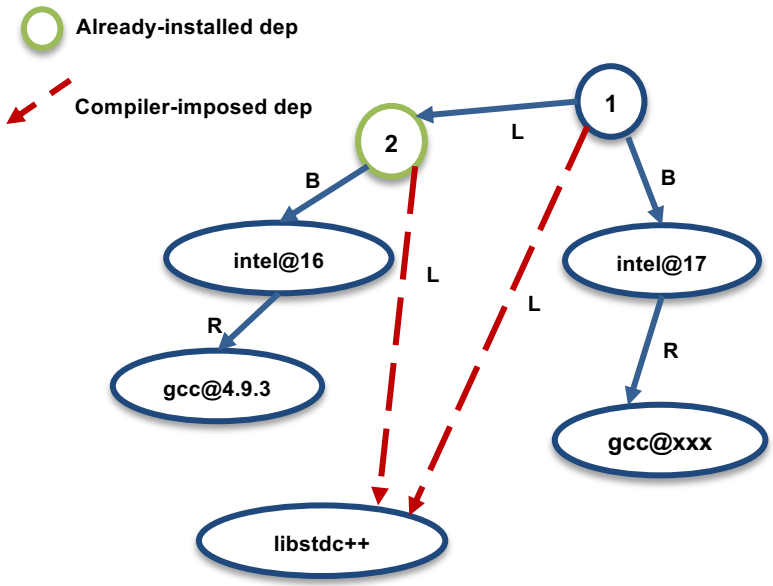
Spack 0.17 Roadmap: permissions and directory structure

- **Sharing a Spack instance**
  - Many users want to be able to install Spack on a cluster and `module load spack`
  - Installations in the Spack prefix are shared among users
  - Users would `spack install` to their home directory by default.
  - This requires us to move most state ***out*** of the Spack prefix
    - Installations would go into ~/.spack/…

- **Getting rid of configuration in ~/.spack**
  - While *installations* may move to the home directory, *configuration* there is causing issues
  - User configuration is like an unwanted global (e.g., LD_LIBRARY_PATH 😬)
    - Interferes with CI builds (many users will `rm -rf ~/.spack` to avoid it)
    - Goes against a lot of our efforts for reproducibility
    - Hard to manage this configuration between multiple machines
  - Environments are a much better fit
    - Make users keep configuration like this in an environment instead of a single config

Spack 0.17 roadmap: compilers as dependencies

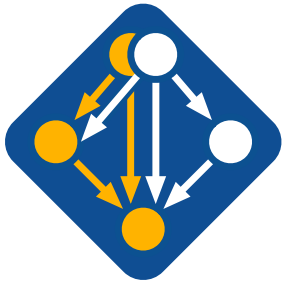
- **We need deeper modeling of compilers to handle complex ABI issues**
  - libstdc++, libc++ compatibility
  - Compilers that depend on compilers
- **Future GPU, OpenMP target, etc. libraries have similar issues**
  - Entire stack for a large code needs to be consistent
  - We currently do not have visibility into what's under the compiler
- **Packages that depend on languages**
  - Depend on **cxx@2011**, **cxx@2017**, **fortran@1995**, etc.
  - Model langauges, openmp, cuda, etc. as virtuals



Compilers and runtime libs fully modeled as dependencies

Join the Spack community!

- There are lots of ways to get involved!
  - Contribute packages, documentation, or features at **github.com/spack/spack**
  - Contribute your configurations to **github.com/spack/spack-configs**



- Talk to us!
  - Join our **Slack channel** (spackpm.herokuapp.com)
  - Join our **Google Group** (see GitHub repo for info)
  - Submit GitHub issues and talk to us!

★ Star us on GitHub!

github.com/spack/spack

Follow us on Twitter!

@spackpm

We hope to make distributing & using HPC software easy!