What’s new in Spack?
New features and the Spack Roadmap

IDEAS Best Practices for HPC Software Developers Webinar
July 15, 2020

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Livermore Computing
Join our virtual Spack tutorial, July 28-29!

- 2 sessions, July 28-29
  - 16:00 – 19:30 CEST (07:00 – 10:30 PST)

- Similar to the tutorials we give at SC, ISC
  - Beginner content on first day
  - Intermediate/advanced on second day

- Teaming up with AWS to offer this event
  - Open to all!

- Register at the URL below

spacktutorialonaws.splashthat.com
Spack provides a spec syntax to describe customized DAG configurations

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

They use a simple Python DSL to define how to build

```python
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='3f7f2ef0d1ba5825780d626741eb0b3f02e0060a8d7ec4794d2a7dfbe2b8ad')
    version('1.2.2', sha256='eaf9d4f562416974157b34d00ca3a1c880fc5296f6e2a2e0a039a86e0976f3a3')
    version('1.1', sha256='232d74072c7b848fa2adc8a1bc839ae8f5f96d50224186601f55554a25f64a')

    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.
        makedirs(prefix.bin)
        install('..',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.

Not shown: patches, resources, conflicts, other directives.
Spack handles combinatorial software complexity.

- Each unique dependency graph is a unique configuration.
- Each configuration installed in a unique directory.
  - 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.

User input: abstract spec with some constraints

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

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.

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

mpi
  +debug
  dyinst

libelf@0.8.11

Detailed provenance is stored with the installed package.

Concretize

---

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

mpi
  +debug
  dyinst

libelf@0.8.11
```

```
- 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

...
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 is used worldwide!

Over 4,300 software packages
Over 2,900 monthly active users (on docs site)

Over 600 contributors from labs, academia, industry

Plot shows sessions on spack.readthedocs.io for one month
Users on our documentation site have also been increasing
Spack is being used on many of the top HPC systems

- Official deployment tool for the U.S. Exascale Computing Project
- 7 of the top 10 supercomputers
- High Energy Physics community
  - Fermilab, CERN, collaborators
- Astra (Sandia)
- Fugaku (Japanese National Supercomputer Project)

Summit (ORNL), Sierra (LLNL)
SuperMUC-NG (LRZ, Germany)
Edison, Cori, Perlmutter (NERSC)
One month of Spack development is pretty busy!

June 13, 2020 – July 13, 2020

Overview

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
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<tbody>
<tr>
<td>Active Pull Requests</td>
<td>398</td>
</tr>
<tr>
<td>Active Issues</td>
<td>111</td>
</tr>
<tr>
<td>Merged Pull Requests</td>
<td>333</td>
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<td>Proposed Pull Requests</td>
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<td>Closed Issues</td>
<td>61</td>
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<tr>
<td>New Issues</td>
<td>50</td>
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Excluding merges, 113 authors have pushed 345 commits to develop and 532 commits to all branches. On develop, 567 files have changed and there have been 16,144 additions and 2,496 deletions.
In November 2015, LLNL provided most of the contributions to Spack.

Since then, we’ve gone from 300 to over 4,000 packages.

Most packages are from external contributors!

Many contributions in core, as well.

We are committed to sustaining Spack’s open source ecosystem!
We are creating GitHub projects (Kanban boards) per release
- Includes major (0.13.0, 0.14.0) and minor (0.13.1, 0.13.2, etc.) releases
- Each release shows the timeframe
- You can easily see what’s on the roadmap!

Makes it easy to rely on release branches
- You can expect us to backport fixes for critical bugs onto these branches

Shooting for quarterly releases
- Expect some movement of features from release to release
- If we don’t finish some things, we’ll move them forward

Per-release Kanban boards allow the community to track releases better!
Spack has stable release branches

- Develop is where most of the action happens
  - Latest commits from pull requests
  - Package updates

- Release branches have release tags, minimize churn
  - Only bugfixes are backported from develop to stable releases
  - Major new features and package recipe changes happen in develop

- releases/v0.14 is the release branch for:
  - v0.14.0
  - v0.14.1
  - v0.14.2
  - Etc.
Spack 0.13 was released in November, at SC19

- **Spack stacks**: combinatorial environments for facility deployment
- Spack detects and builds for **specific microarchitectures**
- **Chaining**: use dependencies from external "upstream" Spack instances
Ever tried to figure out what your processor is?

- You can get a lot of information from:
  - `/proc/cpuinfo` on Linux
  - `sysctl` tool on Macs
- But it’s not exactly intuitive

Humans call this architecture “broadwell”

oh.
Spack now understands specific target microarchitectures

- Spack knows what type of machine you’re on
  - 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 with which flags
  - Determine compatibility
  - Enable creation and reuse of optimized binary packages
  - Easily query available architecture features portable build recipes

```
$ spack install lbann target=cascadelake
$ spack install petsc target=zen2
```

Specialized installations

Simple feature query

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

```
$ spack install lbann target=cascadelake
$ spack install petsc target=zen2
```
Archspec: a library for reasoning about microarchitectures

- 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
  - “Does haswell support AVX-512?” “no.”
- Query compiler flags
  - “How do I compile for broadwell with icc?”
- Python package for now, but we want more bindings!
  - Actual data is in a common JSON file w/schema

ReadTheDocs: archspec.rtfd.io
License: Apache 2.0 OR MIT
pip3 install archspec
Spack environments enable users to build customized stacks from an abstract description

- Allows developers to bundle Spack configuration with their repository
- Can also be used to maintain configuration together with Spack packages.
  - E.g., versioning your own local software stack with consistent compilers/MPI implementations
- Manifest / Lockfile model pioneered by Bundler is becoming standard
  - `spack.yaml` describes project requirements
  - `spack.lock` describes exactly what versions/configurations were installed, allows them to be reproduced.

```
# include external configuration
include:
- ../special-config-directory/
- ./config-file.yaml

# add package specs to the 'specs' list
specs:
- hdf5
- libelf
- openmpi
```

```
"concrete_spec": {
  "b4430e2e5e3e9b5bb3edf3d5a61390b": {
    "hdf5": {
      "version": "1.10.5",
      "arch": {
        "platform": "darwin",
        "platform_os": "darwin",
        "target": "x86_64"
      }
    },
    "compiler": {
      "name": "clang",
      "version": "10.0.0-apple"
    },
    "namespace": "builtin",
    "parameters": {
      "cxx": false,
      "debug": false,
      "threadsafe": false
    }
  }
}
```
We have developed Spack stacks: combinatorial environments for entire facility deployments

- Allow users to easily express a huge cross-product of specs
  - All the packages needed for a facility
  - Generate modules tailored to the site
  - Generate a directory layout to browse the packages

- Build on the environments workflow
  - Manifest + lockfile
  - Lockfile enables reproducibility

- Relocatable binaries allow the same binary to be used in a stack, regular install, or container build.
  - Difference is how the user interacts with the stack
  - Single-PATH stack vs. modules
Spack 0.14.0 was released at the end of February

- Completely reworked **GitLab pipeline generation**
  - `spack ci` command

- **Generate container recipes** from environments
  - `spack containerize` command

- **Distributed/parallel builds**
  - `srun -N 8 spack install`
  - Spack instances coordinate effectively via locks
Spack instances can coordinate with each other using only filesystem locks (no MPI required)
- Independently run instances on login nodes, or
- `srun -N 8 -n 32 spack install -j 16 <package>`
Generate container images from environments (0.14)

- 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 can now 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
Making use of the new workflow

Create PR, or push PR branch

Merge ready

Merge PR

Automated build creates container with contents of mirror

Environment repo

GitLab

“CI/CD” only repo

GitHub
Automated builds using GitLab CI will enable a robust, widely available HPC software ecosystem.

With pipeline efforts at E6 labs, users will no longer need to build their own software for high performance.
Spack 0.15 was released 2 weeks ago

- 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
Spack has had 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
Getting external libraries right is tricky

- Current support for external finding is really for build dependencies

- Can work for dependencies like MPI that have well-defined commands
  - mpicc --showme can be used to query information about libraries
  - Provides well defined versions, link path

- Without this, we’d need to inspect libraries, which hard:
  - Are they built for the right architecture?
  - Are they ABI compatible?
  - What variants are enabled?
  - What version is the library?

- Future work: figure out how to detect more libraries safely
  - Could look at tools like pkg-config for this
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

- 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
The concretizer has gotten pretty complicated

Sources for constraints

- Command Line
- Environments
- Local config
- Defaults
- Package repositories

- Current implementation is ad-hoc:
  - Traverse the DAG
  - Evaluate conditions, add dependencies
  - Fill in defaults from many sources
  - Repeat until DAG doesn’t change

- Issues:
  - Limited support for backtracking causes some graphs to resolve incorrectly
  - Some constraints are strictly ordered
  - Lots of conditional complexity

- Design doesn’t scale to all the criteria
  - Hard to add new features/logic
  - Can be slow
What is managed by dependency managers?

1. What packages does this project depend on?
   - This is a property of the project.
   - Developers determine this

2. What version of each package should I install?
   - Specified by developers of project and dependencies
   - Version pinning may be too specific
   - Leaving version ranges open leaves room for error

Concerns:
- Correct/compatible versions? Developers manage
- Latest vs. most tested version? Developers manage
- Most secure version? Developers manage

It’s hard for developers just to manage packages and versions
With a more diverse ecosystem, there’s more that needs to be managed

- **Build configuration options**
  - Optional features/interfaces
  - Choice of parallelism model
    - OpenMP, CUDA, HIP, etc.

- **Interfaces: which library implementation**
  - MPI: MPICH, OpenMPI, MVAPICH
  - BLAS: OpenBLAS, Intel MKL, ARM math libs, etc.
  - CUDA versions

- **Which compiler**
  - Intel, gcc, PGI, clang, XL, AMD, Cray, NAG, others...
  - Compiler version?
  - Which optimization flags?
  - Which runtime libraries (libstdc++, fortran ABIs)
  - Potentially mixed compilers

- **Microarchitecture**
  - Mostly SIMD instruction features
    - AVX-512, AVX-256, SSE, ARM SVE, etc.
SAT solvers look appealing, but they’re very low-level

Some options:

- **picosat** (used by Conda): basic Boolean SAT solver
  - A basic SAT solver finds *any* valid solution
  - We need to optimize for a lot of different criteria
  - We’d like to be able to use numbers, some math in the solve

- **libsolv**: very targeted towards traditional package model
  - Packages, versions, standard formats, picking latest version

Doing optimization in a SAT solver is hard!

- Conda implements its own math routines in pure SAT
- This is kind of like implementing your own binary adders and multipliers 😊
- Apparently a lot slower than libsolv (cf. Mamba project using libsolv in Conda)
Some higher-level solver options

- **SMT: Satisfiability modulo theories**
  - Z3 seems to be the industry standard: very powerful, very active community
  - Support for integer math, implications, higher level logic operations
  - Support for multi-criteria optimization
  - Traction in the formal verification community
  - Nice high level Python interface
  - Can generate unsatisfiable cores and proofs for error cases (but proofs are complex)

- **ASP: Answer Set Programming (not the other ASP)**
  - Potassco project seems to be the most actively developed/active (and very fast)
  - Nice prolog-like first-order logic syntax; boils down to SAT
  - Support for multi-criteria optimization
  - Python interface
  - No support for generating unsat cores or proofs
We ended up implementing a prototype concretizer in ASP

- 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

- Solve time is much faster than existing concretizer
  - Typically a fraction of a second (so far), plus parsing
  - Can fall off a cliff – it’s NP-complete after all

Some facts for HDF5 package
ASP makes it easy to put the logic in one place

Define the space:
each package must be assigned exactly one version.

Disallow conflicted versions

Minimize the total of all version Weights (more on this later)
Previously complicated logic became very simple

- Every node in the DAG has a compiler and a target architecture
  - Some compilers don’t support generating code for some targets
  - But we want to pick the best target possible for each compiler

- Previously this required some complicated logic mixed in with the rest of the solve

Each node has 1 target assigned

Disallow cases where the compiler doesn’t support the target.

Minimize the total weight of all targets

```
% one target per node -- optimization will pick the "best" one
1 \{ node_target(P, T) : target(T) \} 1 -> node(P).

% can't use targets on node if the compiler for the node doesn't support them
node_target(P, T), not compiler_supports_target(C, V, T),
node_compiler(P, C), node_compiler_version(P, C, V).

% if a target is set explicitly, respect it
node_target(P, T) :- node(P), node_target_set(P, T).

% each node has the weight of its assigned target
node_target_weight(P, N) :- node(P), node_target(P, T), target_weight(T, N).
#minimize{ N@5, P : node_target_weight(P, N) }.
```
It was easy to express what were previously pretty complicated constraints:
- There can be at most one provider of any virtual dependency in the DAG
- Depending on a virtual means you depend on one of its providers
- Preferences for virtuals can come from multiple sources
- Pick the most preferred virtual packages

Each of these sections stands alone and is easy to compose with others

```plaintext
% declared dependencies are real if they're not virtual
depends_on(P, D, T) := declared_dependency(P, D, T), not virtual(D), node(P).

% if you declare a dependency on a virtual, you depend on one of its providers
1 { depends_on(P, Q, T) : provides_virtual(Q, V) } 1 := declared_dependency(P, V, T), virtual(V), node(P).

% if a virtual was required by some root spec, one provider is in the DAG
1 { node(P) : provides_virtual(P, V) } 1 := virtual_node(V).

% for any virtual, there can be at most one provider in the DAG
provider(P, V) := node(P), provides_virtual(P, V).
0 { provider(P, V) : node(P) } 1 := virtual(V).

% give dependents the virtuals they want
provider_weight(D, N)
  := virtual(V), depends_on(P, D), provider(D, V),
  pkg_provider_preference(P, V, D, N).

provider_weight(D, N)
  := virtual(V), depends_on(P, D), provider(D, V),
  not pkg_provider_preference(P, V, D, _),
  default_provider_preference(V, D, N).

% pick most preferred virtual providers
#minimize N \in \mathbb{N} : provider_weight(D, N), root(P, R).
```
Not everything was simple

- The learning curve for ASP is fairly high.
  - If you haven’t been exposed to this before, it can take a while to get in the right mindset

- The shorter the program, the more thought per line
  - The examples before are simple to talk about and they’re easy to maintain
  - Writing all of this from scratch took a lot of thought (at least for me)

- Structuring optimization criteria can be a challenge
  - Took a little while to really think through the implications
  - Maximizing criteria tend to expand the DAG unnecessarily, so had to learn to prefer minimization to maximization for most things.
  - Deciding the order in which to optimize different criteria involves some tradeoffs

- The solver is very aggressive, which can lead to some surprising cases
  - hdf5~mpi ^mpich
Sometimes the solver can be overly aggressive

- Previous solver couldn’t figure out how to toggle build options, e.g.:
  ```
  spack install hdf5 ^mpich
  ```

- This would fail because mpich is optional; it’s only in the DAG if the mpi variant is enabled:
  ```
  spack install hdf5 +mpi ^mpich
  ```

- But the new solver can be too smart for its own good. Consider:
  ```
  spack install hdf5 -mpi ^mpich
  ```

- This quickly finds a really obscure way to depend on MPI:
  ```
  hdf5 → libaec → cmake → libarchive → lz4 → valgrind → mpi
  ```

- Need to disable searches through build dependencies (cmake) to avoid this kind of weirdness
Getting information about errors is still tough

- **Good error messages are important for unsatisfiable cases**
  - Need to be able to tell the user something useful about the problem
  - PubGrub is very good at this

- **PubGrub essentially generates a proof of why the DAG isn’t satisfiable**
  - Tells you the salient constraints, points you to what to change

- **Potassco currently doesn’t have great ways to get this information**
  - No unsatisfiable cores or proofs

- **Z3 has support for proof generation, so we’re looking at trying it**
  - Z3 proofs are complicated; challenge to translate them to good messages
  - This is a work in progress
Spack 0.16 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 0.16 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 languages, openmp, cuda, etc. as virtuals
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PubGrub

- Natalie Weizenbaum implemented awesome error reporting in Pub, the package manager for Dart

- Builds on a basic CDCL SAT solver with a data structure to keep track of conflicts and to generate great error messages
  - Model of PubGrub so far seems to be package/version
  - Has some custom callbacks to evaluate version constraints

- Optimization is done by exploring versions in order
  - We need multi-criteria optimization – more complex tactics
  - Lots of peoples’ life work has gone into faster solvers than we think we could implement ourselves.

- Worried about implementing a custom solver in Python
  - We’re solving more complex problems than most tools
  - Poetry, other Python-native solvers can already be quite slow, and they only deal with packages and versions