Learning to Predict and Improve Build Successes in Package Ecosystems

Harshitha Menon, Todd Gamblin
Lawrence Livermore National Laboratory

BUILD-SI

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We build codes from hundreds of small, complex pieces

- Component-based software development dates back to the 60's
- M.D. McIlroy, Mass Produced Software Components. NATO SE Conf., 1968
- Pros are well known:
  - Teams can and must reuse each others' work
  - Teams write less code, meet deliverables faster
- Cons:
  - Teams must ensure that components work together
  - Integration burden increases with each additional library
  - Integration must be repeated with each update to components

Developers integrate large software stacks manually

- Simply finding a compatible set of versions for packages is NP-hard (combinatorial)
  - Changing one version may affect all others, those changes may trigger others, and so on
- In HPC, there are many more parameters to adjust
  - Version, compiler, ABI, build options, microarchitecture, GPU capability, etc.
  - Multiple codes in the same environment (workflows), performance
- We solve this problem repeatedly by trial and error
  - Incompatibilities are not known in advance; developers discover them

Transitive dependency requirements can cause cascading errors

```
       umpire                                    umpire
     /        \          upgrade               /        \
camp@1.0    blt@1.0        --->         camp@1.1    blt@1.1
     \        /                                \        /
     cmake@3.19                               cmake@3.21.0
```

- blt@1.0 requires cmake >= 3.18, but is incompatible with cmake@3.21.0 due to an unknown bug
- camp@1.0 depends on cmake@3.19 or higher, but camp@1.1 depends on cmake@3.21 or higher
- The umpire developers want to use camp@1.1 for its new features
- Upgrading camp to 1.1 pushes cmake to the latest 3.21.0 will cause the build to fail
- We need to use blt@1.1 to make this work.

Team would have to build several versions of cmake and blt to find a working configuration

BuildCheck

Predict the build outcome of various package configurations with high accuracy.

Graph Neural Networks (GNN) for Build Prediction

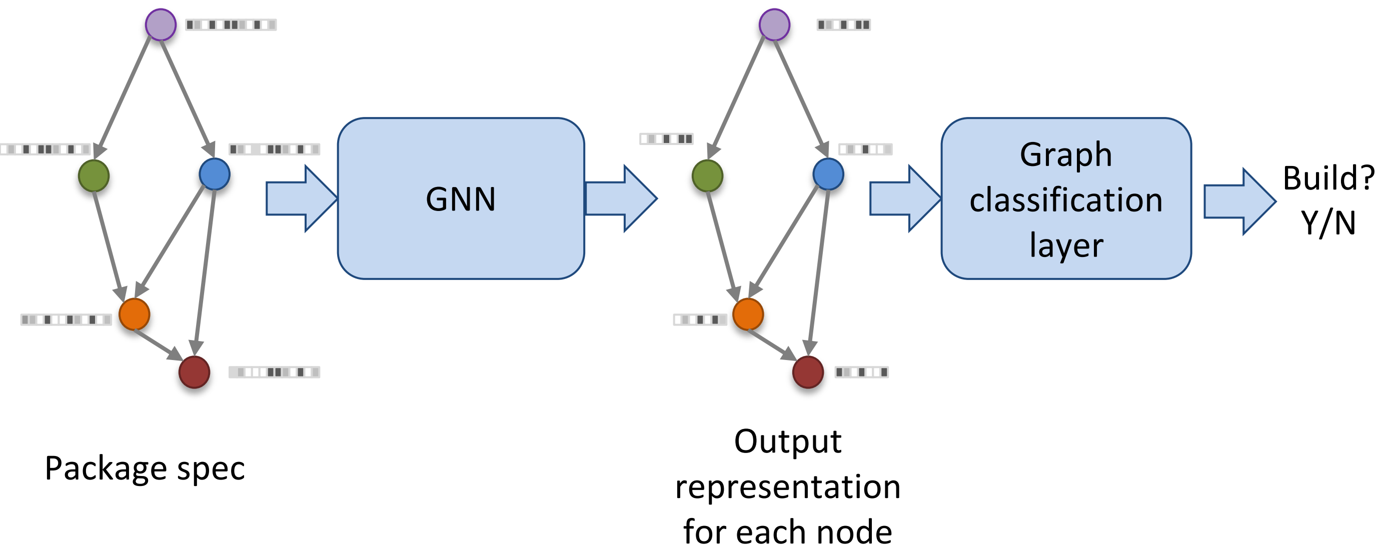
Why GNN?

- GNNs are ideally suited for handling complex dependency relationships in software ecosystems.

Problem Definition

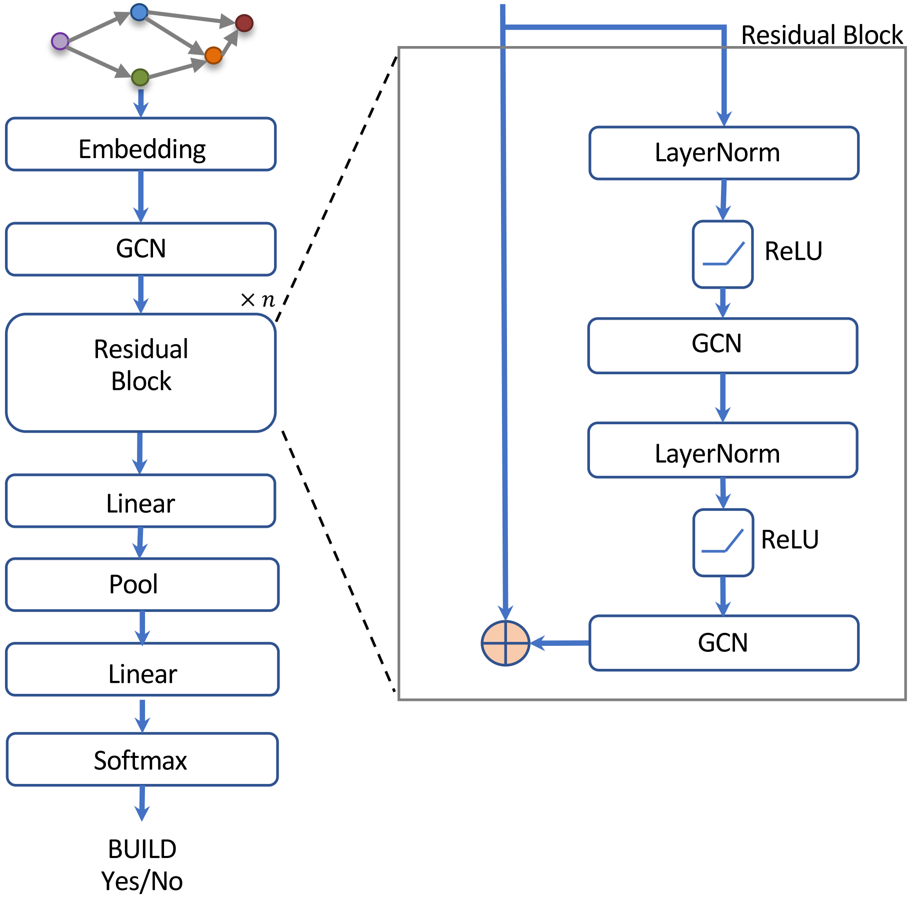
- The package dependency graph is a directed acyclic graph (DAG)
- Graph is represented as $G = (V, E)$, where V is the set of nodes representing the packages and E is the set of edges capturing the dependencies.
- We cast the build success prediction problem as a supervised learning problem
- **Goal**: learn a model to predict the build outcome

Overview of build outcome prediction using GNN



- Each configuration is represented as a graph
- Node features incorporate information about packages (which package and version)
- Layers GCN
- Final layer does a global pooling to predict whether this configuration builds or not.

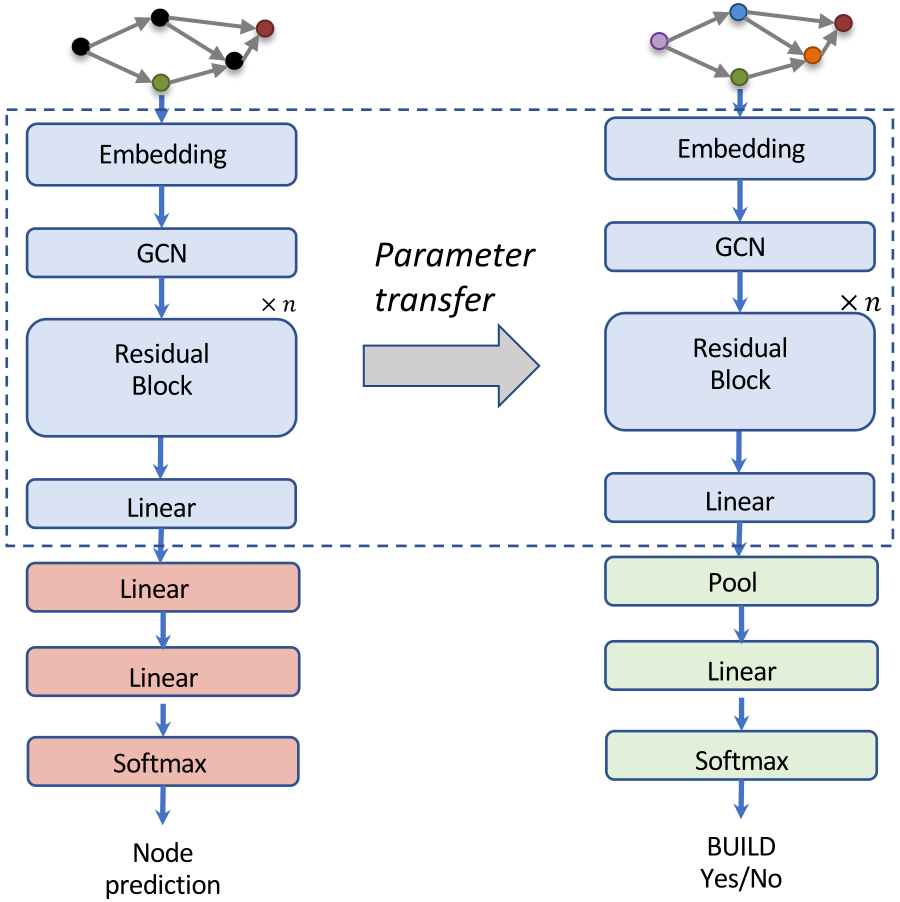
BuildCheck GNN Architecture

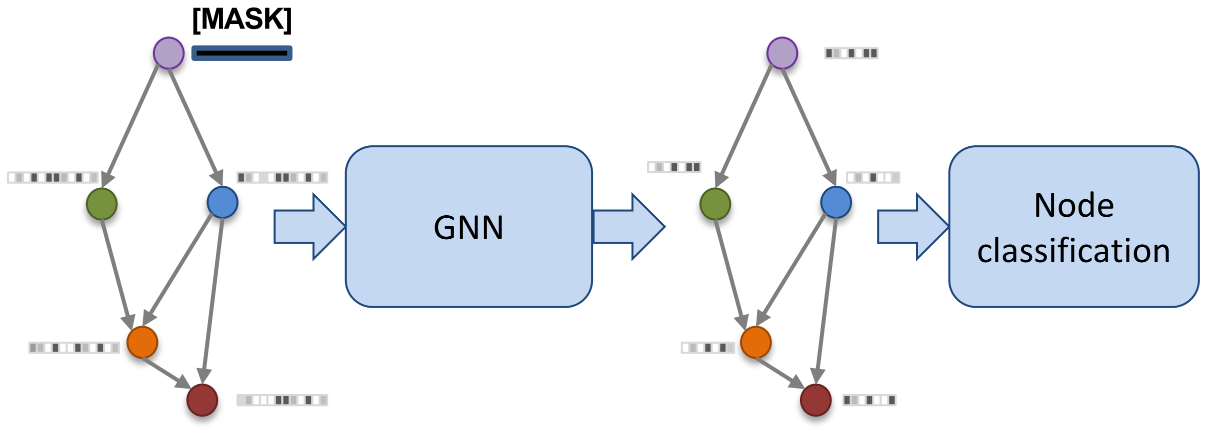


Main Components

- Multiple Graph Convolutional layers.
- Embedding layer: maps package information into a continuous vector space
- Residual block: aids in training deeper networks.
- Pool layer: computes the average of all node features and creates a representation of the entire graph

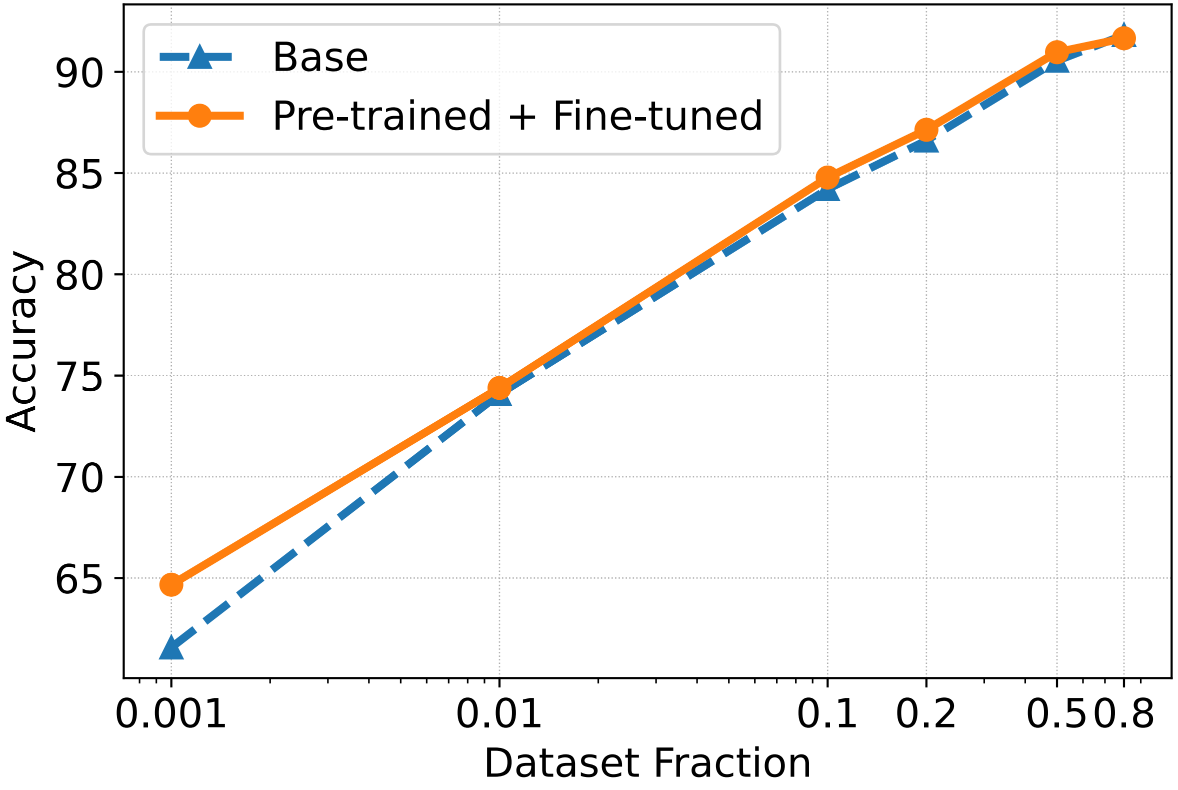
Self-Supervised Pretraining Task for Learning Node Embeddings for Downstream tasks

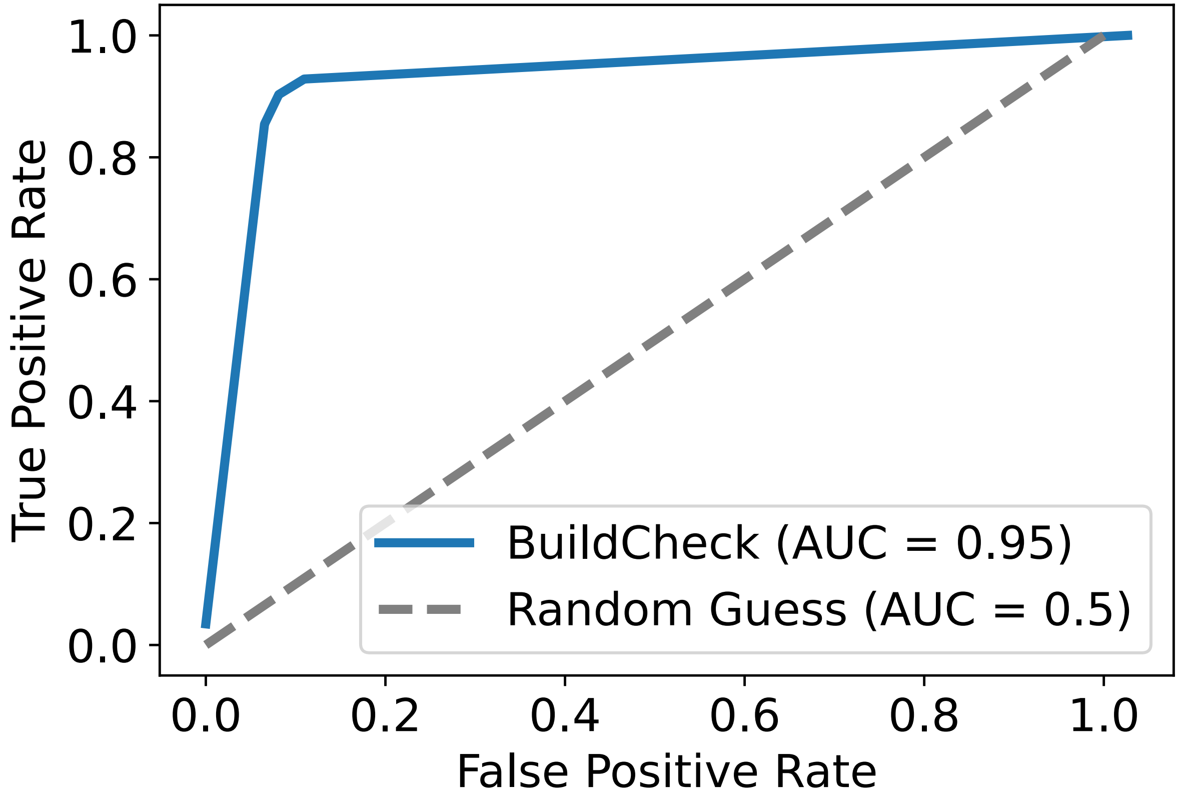




Pre-trained package dependency model can be used for build prediction with fine-tuning

Evaluation





Our model achieves an accuracy of 91% on E4S build dataset

Conclusion and Ongoing Work

- Demonstrated how to combine the capabilities of Graph Neural Networks and advanced package management technologies to offer practical solutions for managing package dependencies
- BuildCheck can eliminate very expensive trial-and-error exercise to find working builds
- Use the outputs of BuildCheck in Spack's concretizer solver
- Using GNN Explainer to explain the reason for build failure prediction
- Integrate the model with the Spack's Continuous Integration system

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