Carnegie Mellon University
Software Engineering Institute

Advancing Algorithms For File Deduplication Across Containers

NOVEMBER 14–16, 2022

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Document Markings

This material is based upon work funded and supported by the Department of Defense under Contract No. FA8702-15-D-0002 with Carnegie Mellon University for the operation of the Software Engineering Institute, a federally funded research and development center.

DM22-0864

Introduction

Problem: The self-contained nature of container images leads to storage waste, which conflicts with resource limitations at the edge.

Solution: Develop an automated technology that minimizes the storage size of a set of container images for developers to use before deployment to the edge.

Impact: The technology allows DoD organizations to field more capability per SWaP at faster deployment speeds.

Storage Waste in Container Images

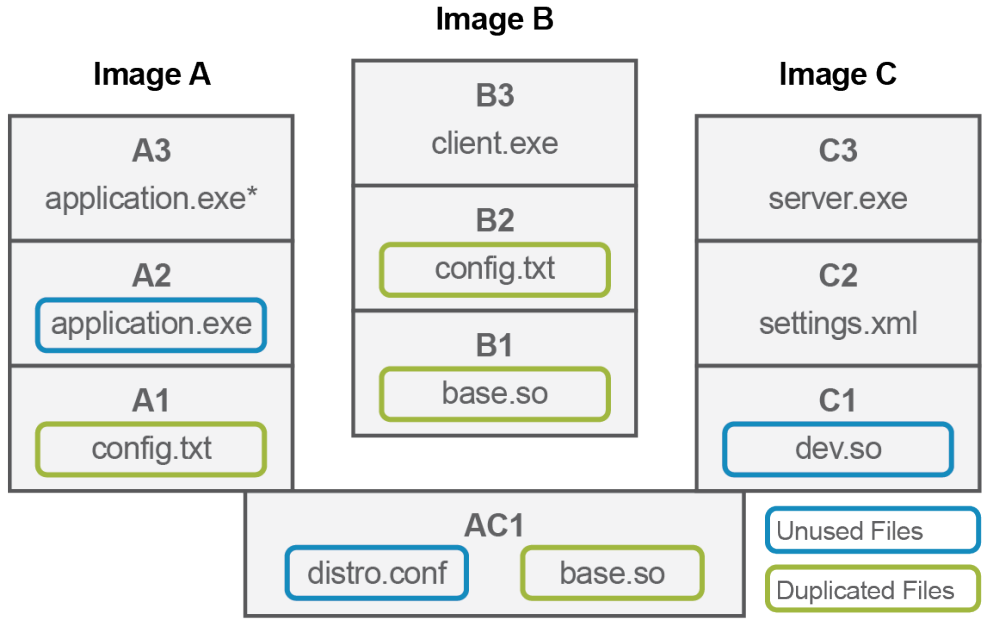
Sources of Storage Waste

unused files

- development files (dev.so)
  - unused distro files (distro.conf)
  - overwritten files (application.exe)

duplicated files

- same files stored in different layers

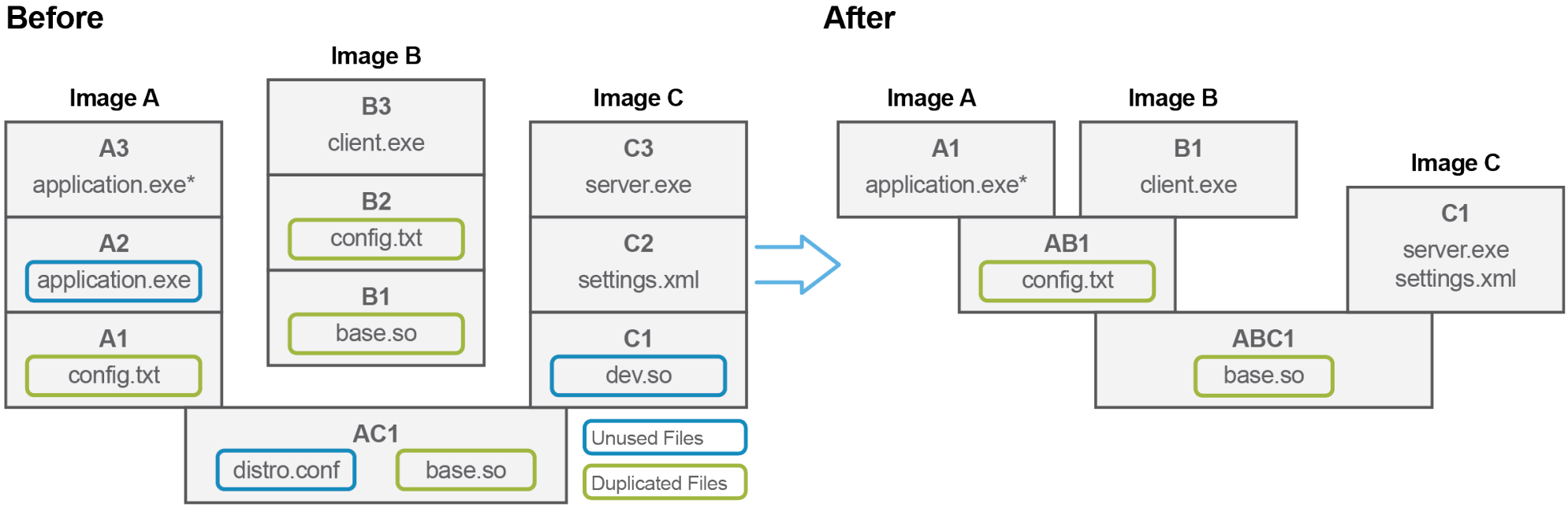


Minimization Terminology

- *pruning* – the removal of unnecessary and unused files from containers
- *deduplication* - combining shared files from multiple images into common container layers

Container Minimization Tool (CMT)

Develop an automated technology that minimizes the storage size of a set of container images that developers can use before deployment to the edge.



Deduplication Algorithm

Overview

Objective: Develop a file deduplication algorithm for reorganizing the layers for a set of images to reduce storage and network costs

- method proposed by Skourtis[1]
- structured as an optimization problem to minimize value of cost function

cost = α*operation

- Cost of too many layers

+ β*storage

- Cost of duplicate files in layers

+ γ*network

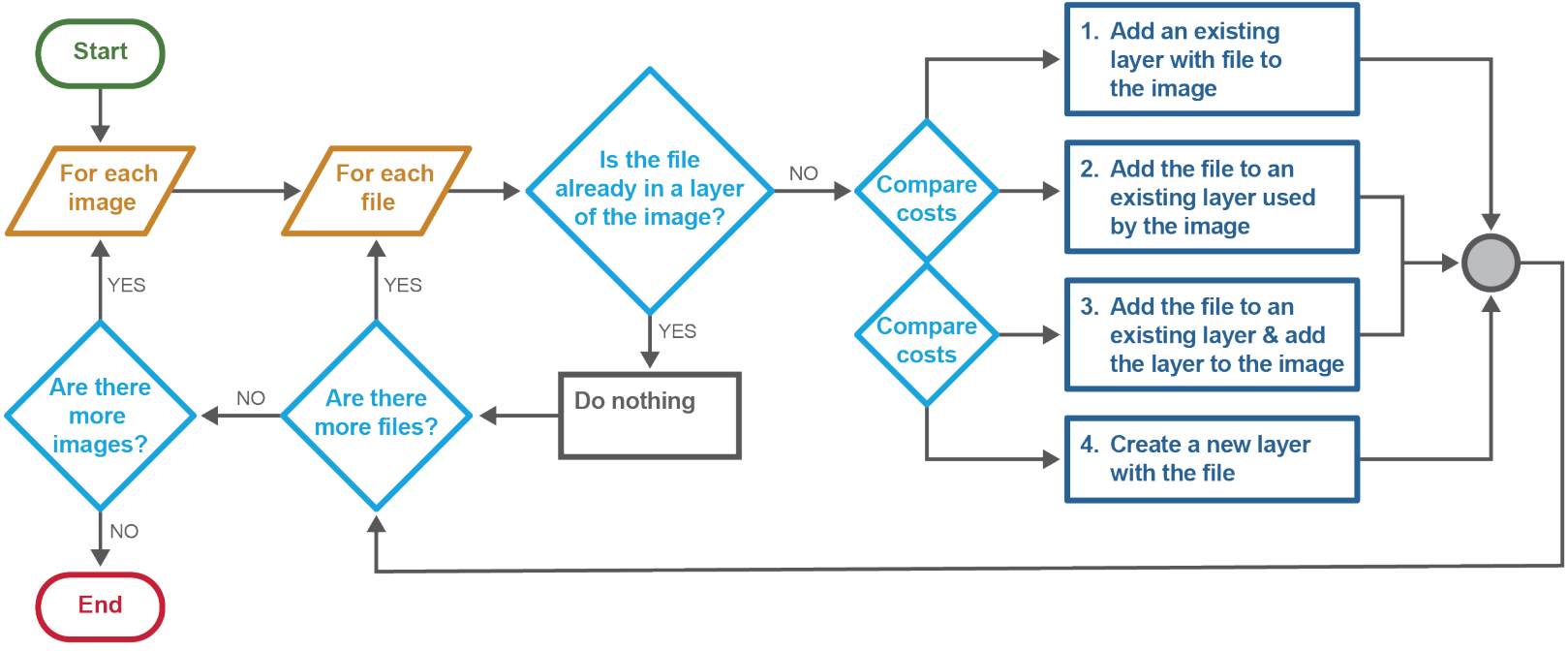
- Cost of too few layers

[1] Skourtis et al. Carving Perfect Layers out of Docker Images. 2019. https://www.usenix.org/system/files/hotcloud19-paper-skourtis_0.pdf

Deduplication Algorithm

Steps

The solution is a greedy algorithm that creates a new set of layers for every image with minimal duplicates.



Deduplication Algorithm

Challenges

- The authors did not release the code.

- The authors implemented an abstract, simplified algorithm with no output of real images.
  - ignores the complexity of creating working final images

- The authors did not release benchmark information on how long it takes to run the algorithm.

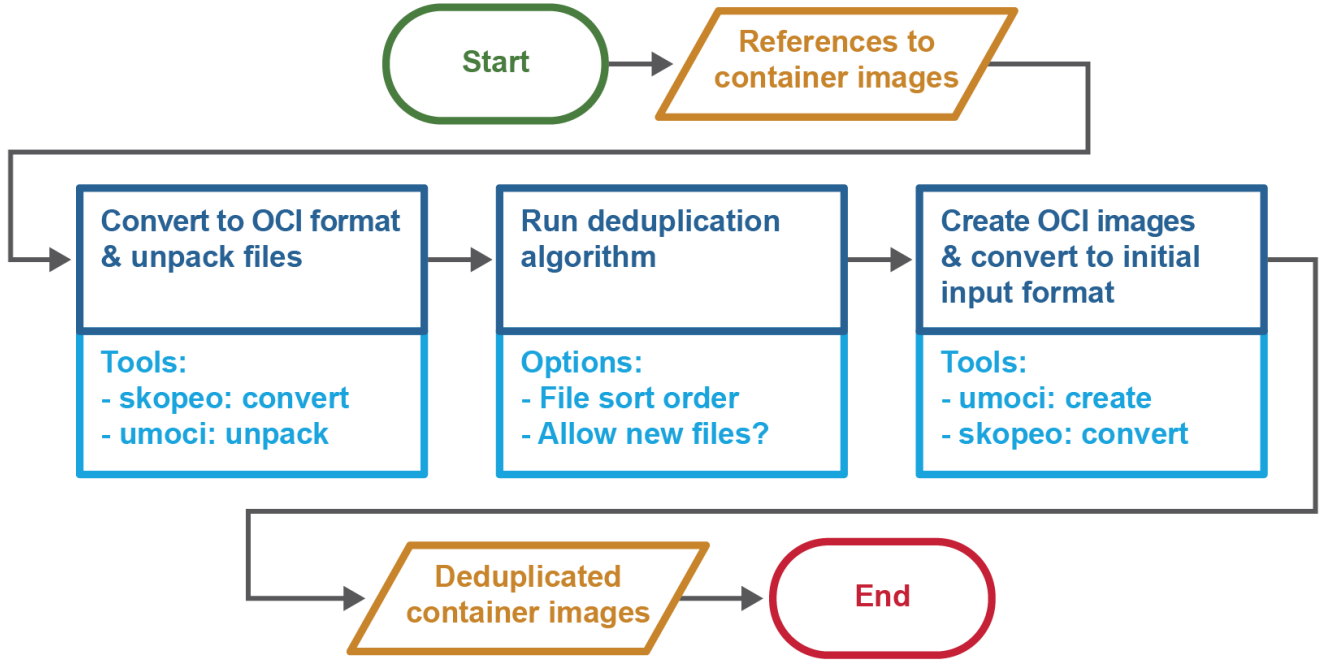
Implementation

Create end-to-end tool that deduplicates images.

- *input:* references to container images
- *output:* deduplicated container images

Utilize OCI image format to increase applicability.

- Use open source tools skopeo & umoci



Experiments

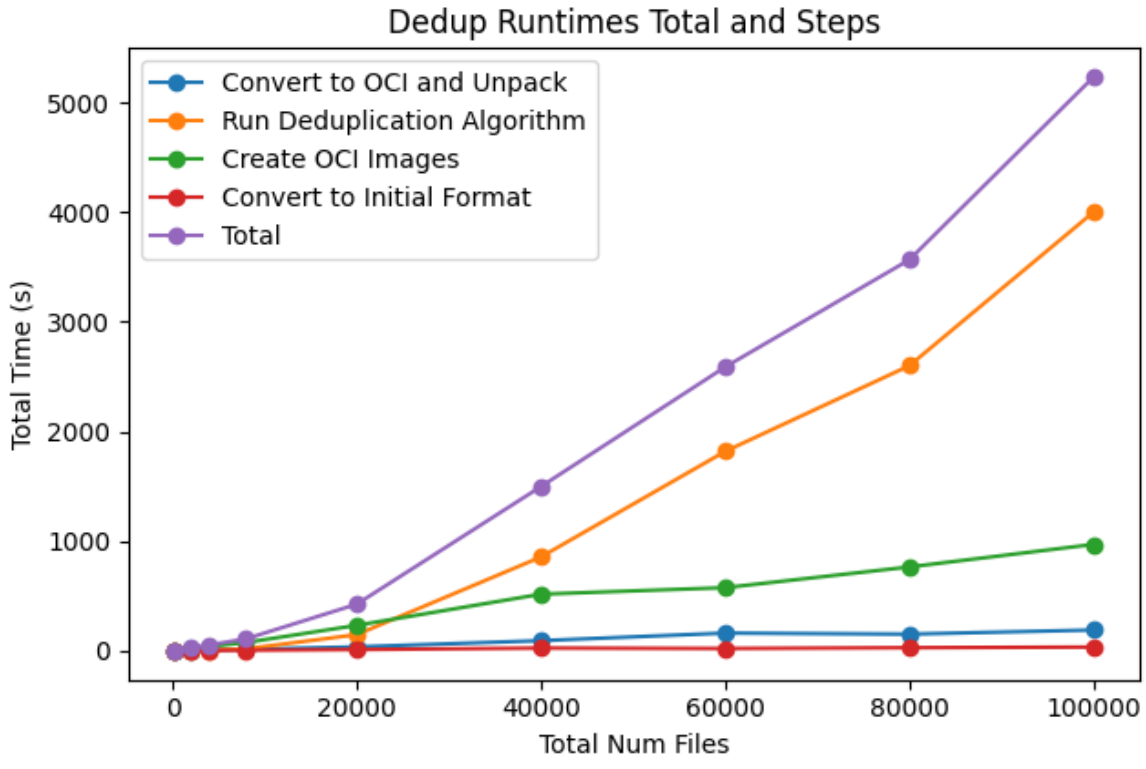
Time Profiling

Goal: Measure effect of number of files on time needed to deduplicate.

- 2 images
- equal number of files per image
- 10 files duplicated between images

Results:

- The time is $O(n^2)$ on number of files.
- ”Run Deduplication Algorithm” takes the largest percentage of time.
- After multiple optimizations, we reduced algorithm runtime by 30x from our initial implementation.



Experiments

Deduplication Evaluation

Goal: To measure the ability to deduplicate depending on amount of duplicated files

- We generated images with different percentages of duplicated files (size 100kb) for two images: 0% to 100%.
- We kept the total number of files (1000 files) constant between experiments.

Results:

- For all cases, duplication is 0% for all deduplicated images.

Experiments
Real Images

We ran both the time profiling and deduplication evaluation experiments on real sets of images.

Test Case 1: ClearML[1]

- 5 unique images (8 services)
- 64,138 files (2872 MB)
  - 3,948 shared files (25.2 MB)
  - All of them are duplicated

Results:

- The method deduplicated images in 24 minutes (on server with 3.1 Ghz Xeon processor).
- The method achieved full deduplication when files were processed in order of most used.
  - 2872 MB => 2847 MB
- When files were processed alphabetically, results were worse (only 1.9 MB of 25.2 MB deduplicated).

[1] https://clear.ml/

Experiments
Real Images

We ran both the time profiling and deduplication evaluation experiments on real sets of images.

Test Case 2: Stan's Robot Shop[1]

- 10 unique images (10 services)
- 225,915 files (4.62 GB)
  - 112,687 shared files (3.3 GB)
  - 27,033 of those are duplicated (724 MB)

Results:

- The method deduplicated images in 81 minutes (on server with 3.1Ghz Xeon processor).
- The method achieved full deduplication when files were processed in order of most used.
  - 4.62 GB => 3.89 GB
- When files were processed alphabetically, results were worse (only 77 MB of 724 MB deduplicated).

[1] https://github.com/instana/robot-shop

Use Cases for DoD Systems

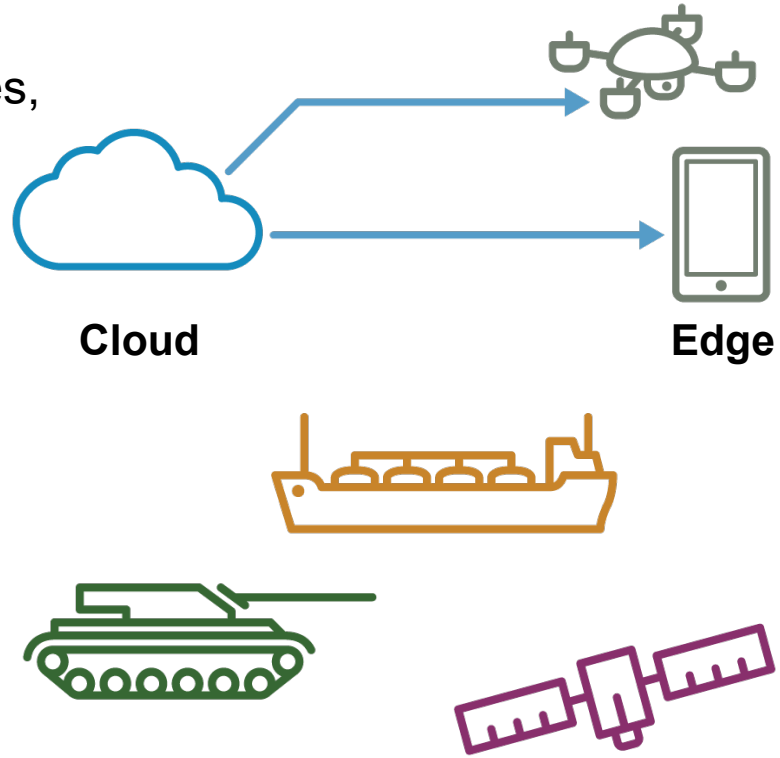
Who: organizations deploying containers to very SWAP-constrained edge systems (e.g., legacy systems, satellites, drones, etc.)

When: Organizations can use image deduplication

- when existing build practices utilize different kinds of base images.
- when container images from multiple organizations are deployed together.
- after pruning container images to rebuild shared base layers.

Why: Our results indicate that we can reduce container image storage usage and update bandwidth.

- by up to 5-15% for multi-container deployments
- by up to 10-30% for pruned container deployments



Next Steps

Algorithm

- Increase algorithm speed to accommodate larger sets of images (e.g., parallelize).
- Add an optimized special case when developers update only a subset of images.

Testing

- Test and evaluate the algorithm with other sets of real-world images.
  - More images/files, higher duplication percentage

Release

- Put code through release review and release it on GitHub.
- Publish testing results.

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