CSc 553 — Principles of Compilation

12 : Garbage Collection — The Train Algorithm

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Train Algorithm

- The generation algorithm
  1. works well for immature objects
  2. works less well for mature objects — every time the generation they're in is garbage collected, they get moved!
- The train algorithm was designed to handle mature objects well.
- Unlike the generational algorithm, the train algorithm never needs to collect the entire heap.

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Train Algorithm — Basic Idea

- Split memory into small blocks.
- Perform a copy-collection-type garbage collection seperately for each block.
- We get shorter pauses since the size of the blocks is small.
- Since we're only collecting a part of the entire heap at a time, we need to use *remembered sets* (just like for generational collection) to handle references between blocks.

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Combining Algorithms

- Combine the train and generational algorithms:
  1. Use the generational algorithm for immature objects;
  2. When an object has survived a few collections, move it to a different head managed by the train algorithm,

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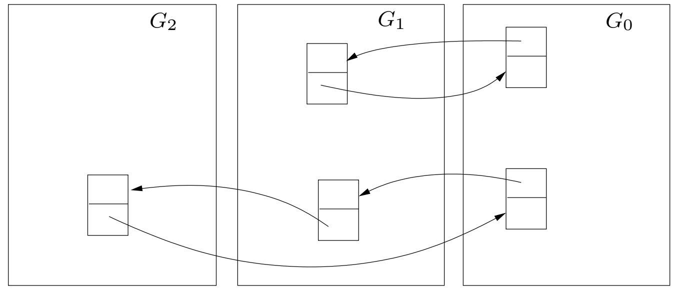

Multi-Generation Cycles

- In the generational algorithm we must occasionally collect the entire heap, or we may miss cyclic garbage.

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Train Algorithm

- Fixed sized partions called *cars* — the size of one (or more) disk blocks.
- Cars are organized into *trains*.
- No limit on the number of trains.
- No limit on the number of cars per train.

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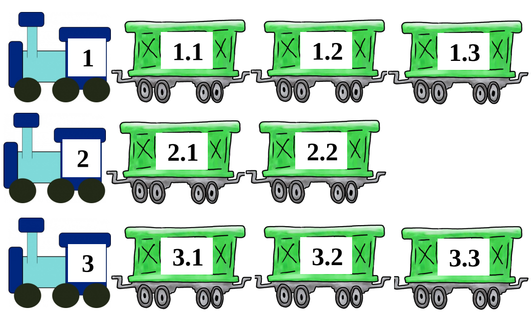
Train Organization



- Trains are numbered $1, 2, 3, \ldots$.
- Cars are numbered $\langle train - number \rangle . \langle car - number \rangle$.
- Trains and cars are ordered lexicographically, i.e. $1.1, 1.2, 1.3, \ldots, 2.1, 2.2, 2.3, \ldots, 3.1, 3.2, 3.3, \ldots$.

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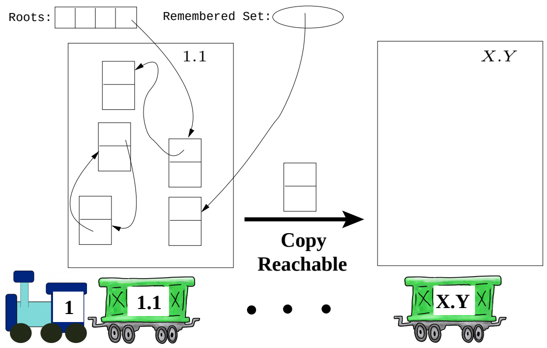
Train Algorithm — Case 1



- Car 1.1 is collected. Unreachable objects, including cycles contained within the car, are identified.
- Reachable objects are moved to some other car.
- The car becomes empty and is removed from the train.

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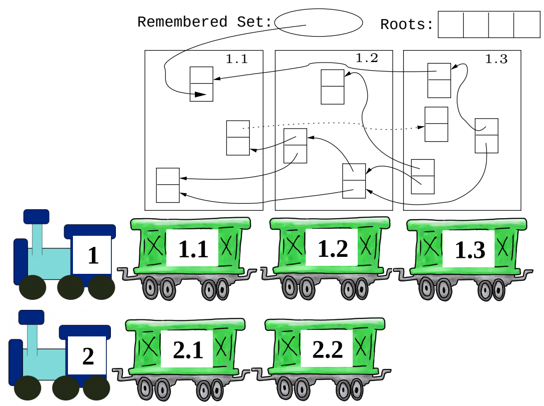

Train Algorithm — Case 2

- No root pointers point to train 1.
- The remembered set for train 1 only has pointers from cars of the same train.
- All cycles are contained in train 1 ⇒ Delete train 1!

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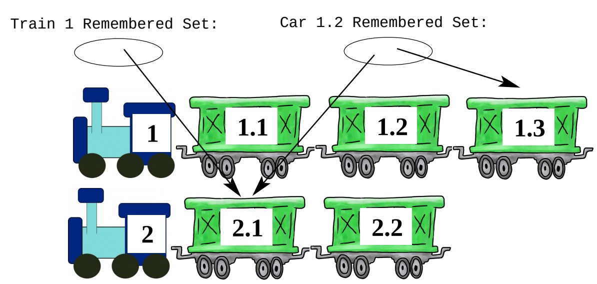

Train Algorithm — Remembered Sets

- Each car's remembered set contains pointers to objects in higher numbered cars in the same train and higher-numbered trains.
- Each train's remembered sets contains pointers to objects in higher-numbered trains.

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Allocating Objects and Managing Trains

- The goal is to move out of train one everything that's not cyclic garbage.
- When a train is just cyclic garbage, we throw it away.
- Create a new train every k object creations.
- On `o` $\leftarrow$ `new T` we could add o to
  1. the last car of the last train, if there's room, or
  2. a new last car of last train, or
  3. the first car of a new last train.

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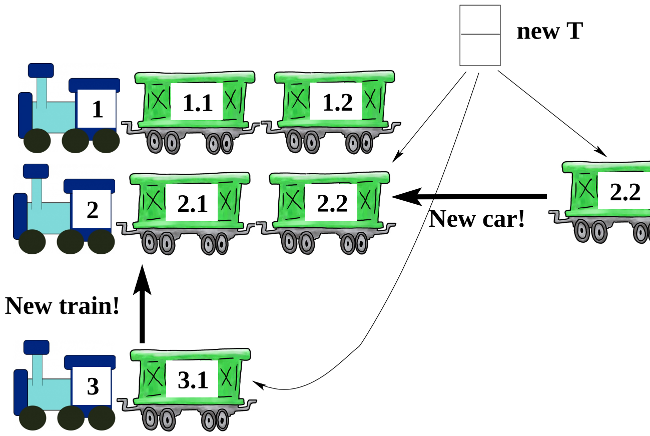

Allocating Objects and Managing Trains...

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Garbage Collecting a Car

1. Consider Car 1.1's remembered set and the roots.
2. Scan objects within the car.
3. Move reachable object o to another car c:
   - If the remembered set says o is referenced from some other (higher-numbered) train, move o to some car c in that train. Pick a car that references o (good for locality). If there's no room, add a new car.
   - If no other train references o, move c to another car within the same train. Prefer a car that references o — this will move cyclic structures to the same car. If there's no room, move c to a new last car.
4. Remove car 1.1.

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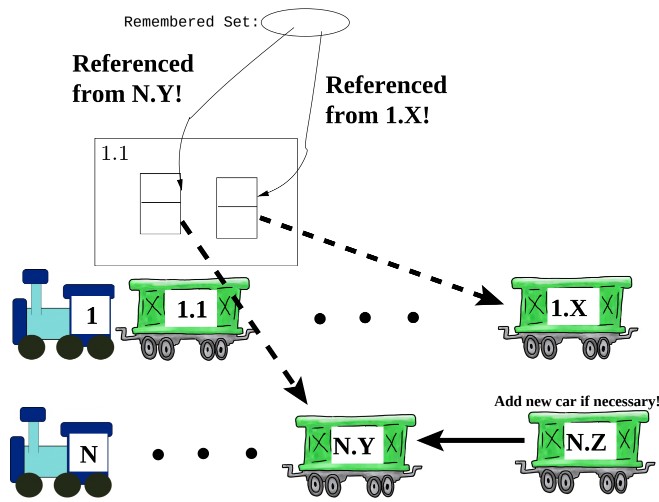
Garbage Collecting a Car. . .



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Garbage Collecting a Train

- Eventually, all the cars in Train 1 will have been removed ⇒ remove Train 1.
- Therefore, eventually, every train becomes the first train, and its cars get garbage collected.

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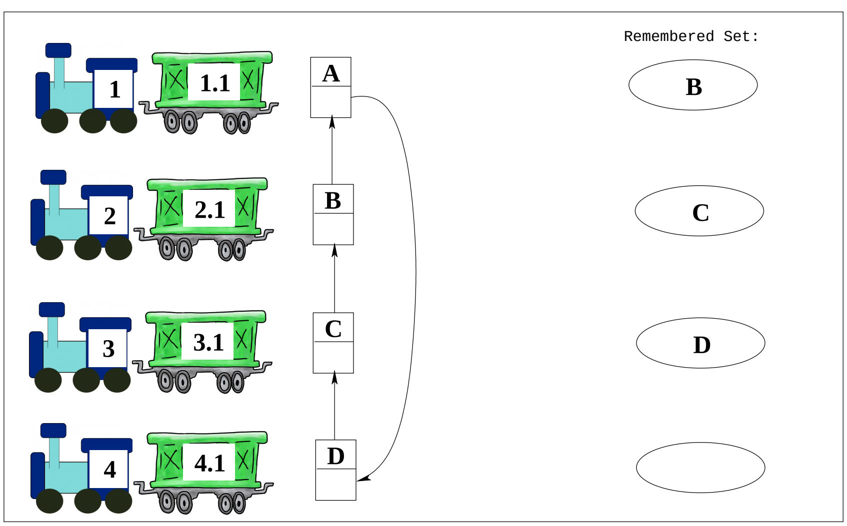
Example 1 — Step 1



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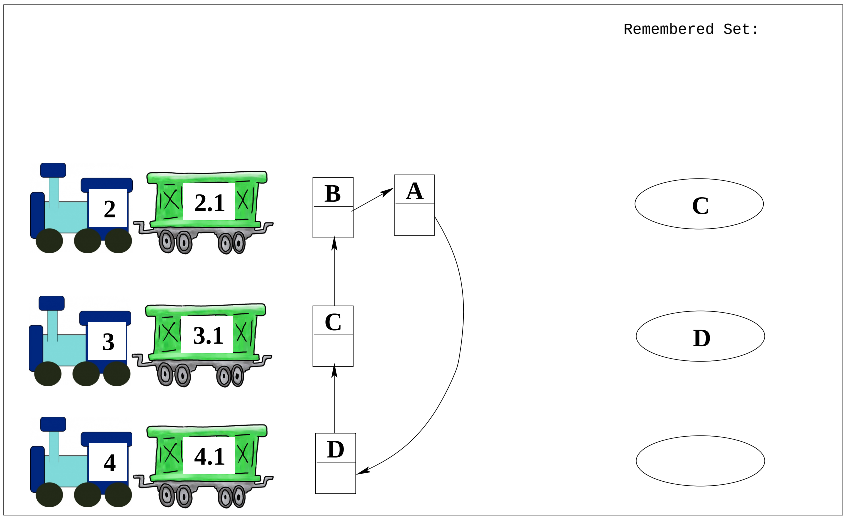

Example 1 — Step 2

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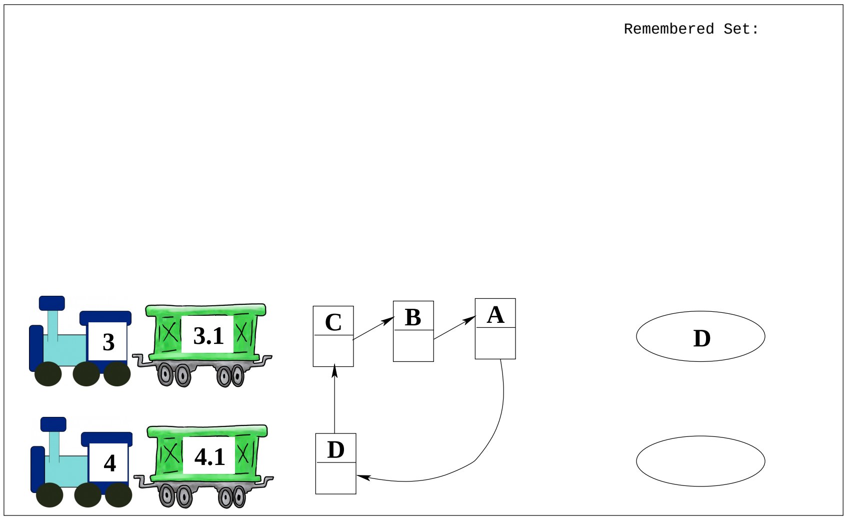

Example 1 — Step 3

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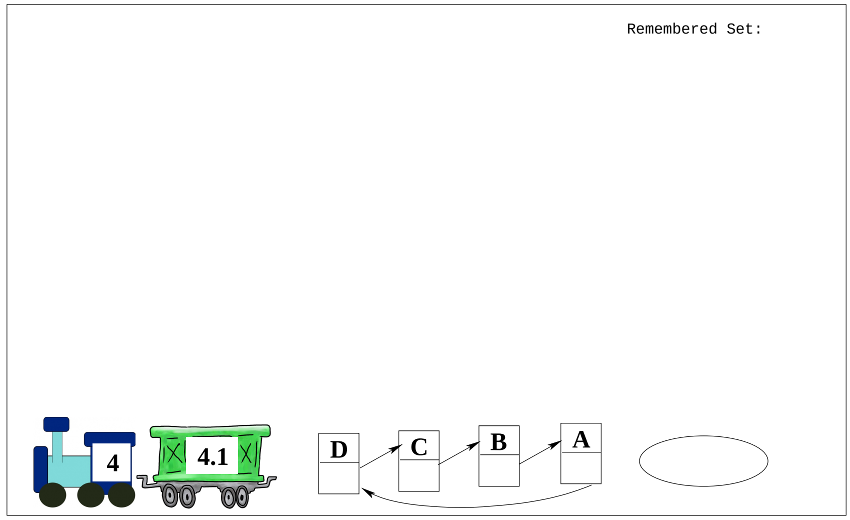

Example 1 — Step 4

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Example 1 — Step 5

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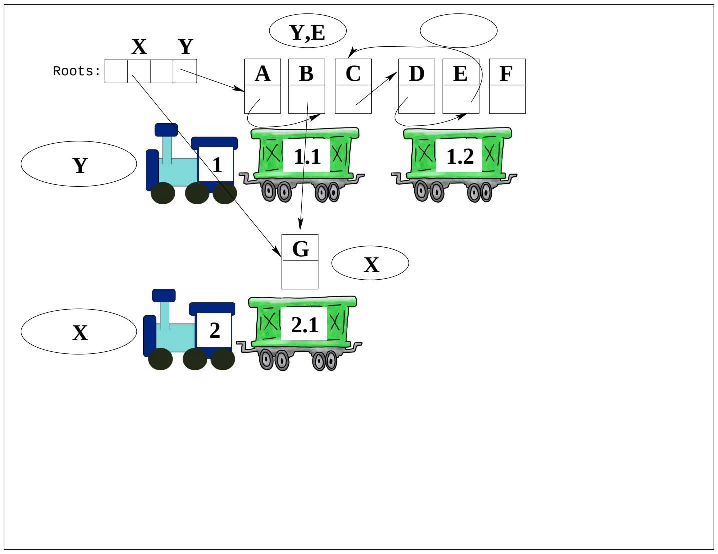

Example 2 — Step 1

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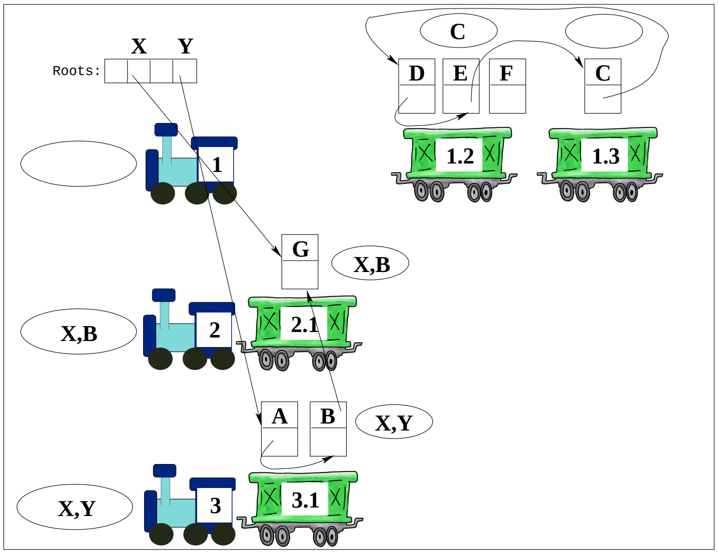

Example 2 — Step 2

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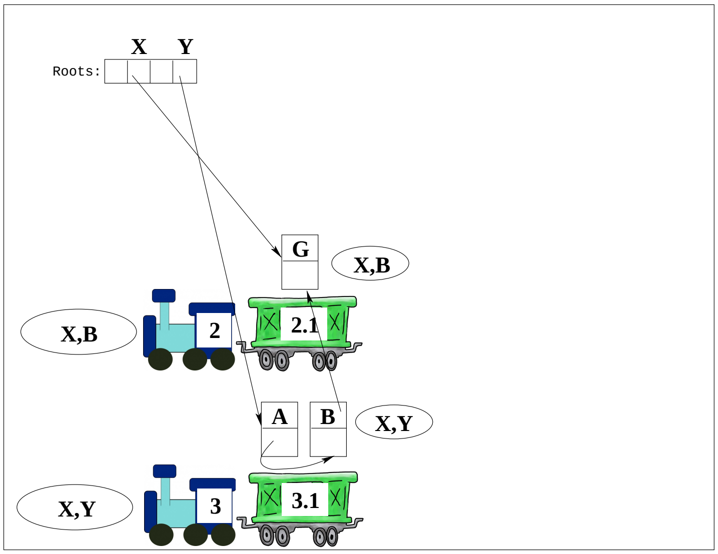

Example 2 — Step 3

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Really Large Objects

- Since cars are fixed size (maybe the size of a memory page) there may be really large blocks that don't fit.
- Use a special heap for such large objects.

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Readings and References

- Read Aho, Lam, Sethi, Ullman, Section 7.7.5
- Incremental Garbage Collection: The Train Algorithm, Thomas Würthinger: `http://www.ssw.uni-linz.ac.at/General/Staff/TW/Wuerthinger05Train.pdf`