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Java

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The Ghost in the Virtual Machine
A Reference to References

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Google Inc.

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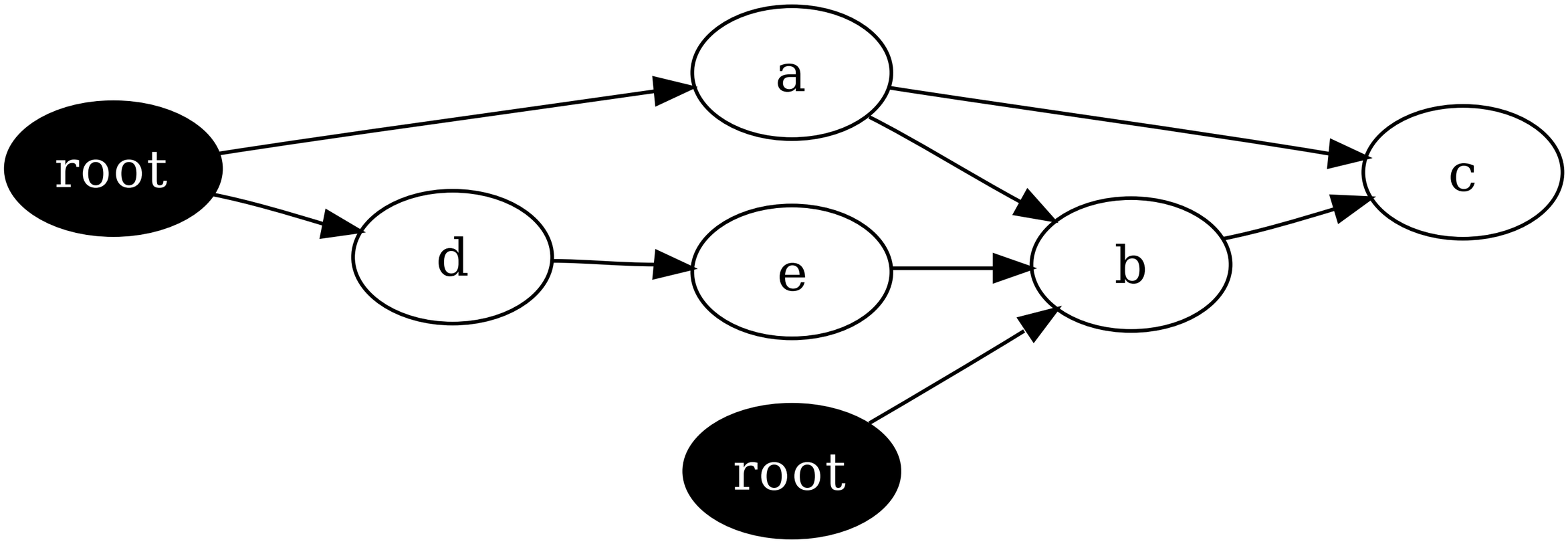
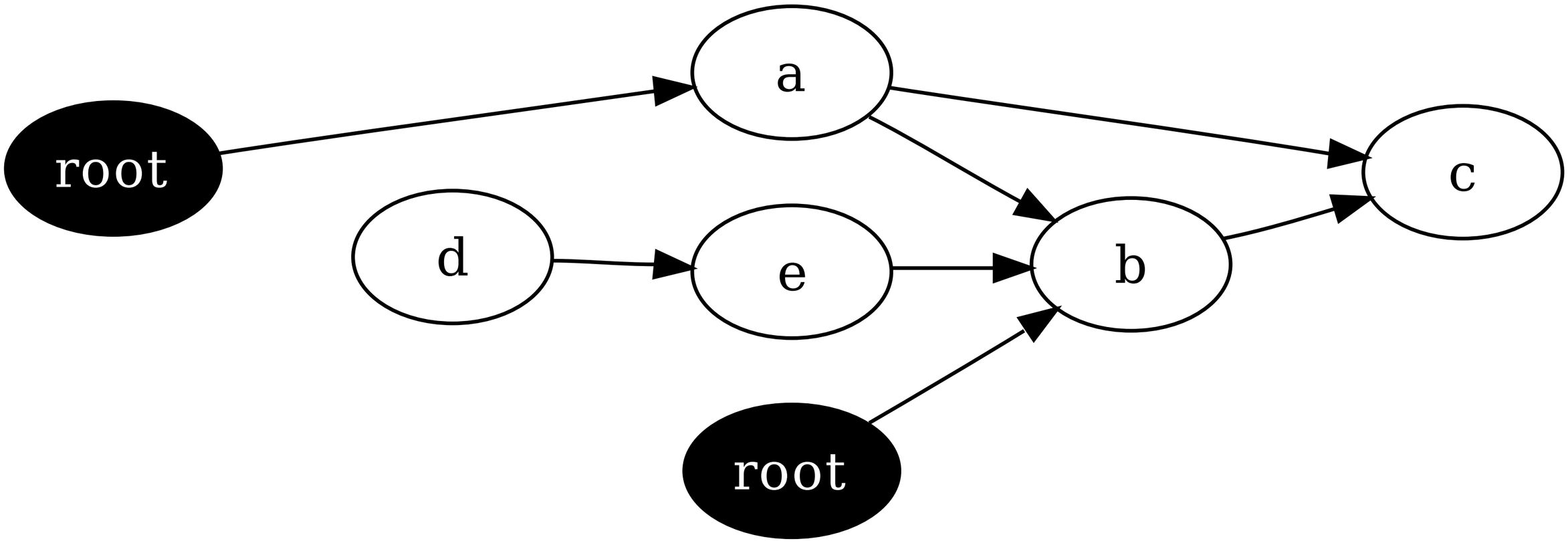
Goals

- Take the mystery out of garbage collection.
- Perform manual cleanup the Right way.
- Become honorary VM sanitation engineers.

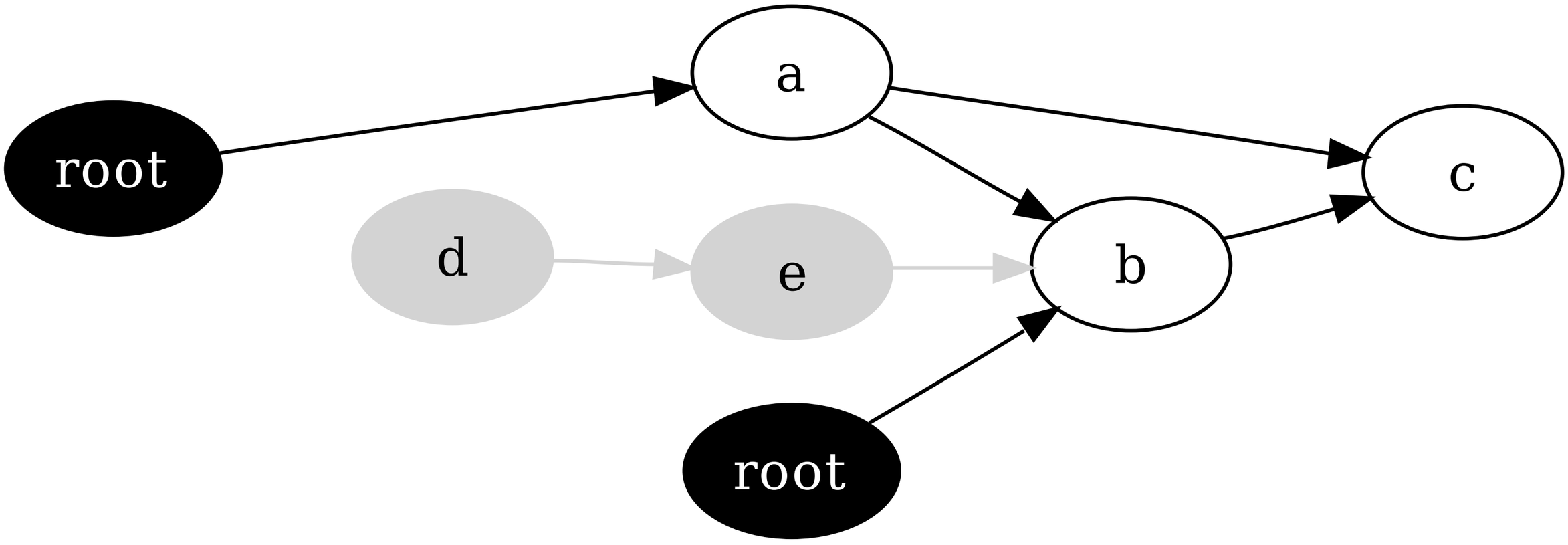
How does garbage collection work?



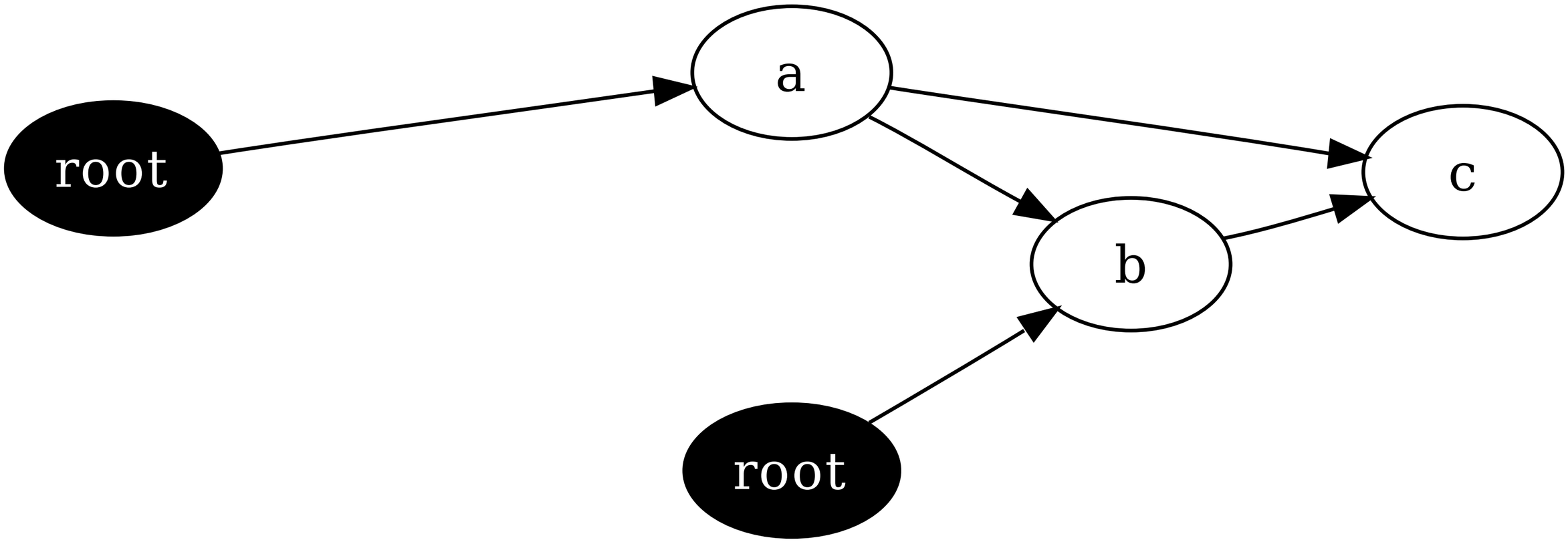
If the reference to D goes away...



We can no longer reach D or E.



So the collector reclaims them.



The GC can't do everything.

- Some things require manual cleanup.
  - Listeners
  - File descriptors
  - Native memory
  - External state (`IdentityHashMap`)
- Tools at your disposal:
  - `finally`
  - Overriding `Object.finalize()`
  - Reference queues

Try `finally` first.

> Reasons to not use `finally`:

- More work for programmers
- More error prone
- Cleanup happens in main thread

> ARM will help.

What is a finalizer?

```
public class Foo extends Bar {
  @Override protected void finalize() throws Throwable {
    try {
      ... // Clean up Foo.
    } finally {
      super.finalize(); // Clean up Bar.
    }
  }
}
```

Finalizers are seductively simple, but...

- They're not guaranteed to run, especially not timely.
- Avoid `System.runFinalizersOnExit()` and `runFinalization()`.
- Undefined threading model, can run concurrently!
- You must call `super.finalize()`.
- Exceptions are ignored (per spec).
- You can resurrect references.
- Keeps objects alive longer.
- Can make allocation/reclamation 430X slower (Bloch, Effective Java)

An external resource

```
public class NativeMemory {
  final int address = allocate();
  /** Allocates native memory. */
  static native int allocate();

  /** Writes to native memory. */
  public void write(byte[] data) {
    write(address, data);
  }
  static native void write(int address, byte[] data);

  /** Frees native memory. */
  @Override protected void finalize() {
    free(address);
  }
  static native void free(int address);
}
```

Let's play War!

`SegfaultFactory` can cause a segfault if its finalizer executes after `NativeResource`'s.

```
public class SegfaultFactory {
  private final NativeMemory nm;

  public SegfaultFactory(NativeMemory nm) {
    this.nm = nm;
  }

  @Override protected void finalize() {
    // 50/50 chance of failure
    nm.write("I'm taking the VM with me!".getBytes());
  }
}
```

Use protection.

```
public class NativeMemory {
  final int address = allocate();
  /** Allocates native memory. */
  static native int allocate();

  /** Writes to native memory. */
  boolean finalized;
  public synchronized void write(byte[] data) {
    if (!finalized) write(address, data);
    else /* do nothing? */;
  }
  static native void write(int address, byte[] data);

  /** Frees native memory. */
  @Override protected synchronized void finalize() {
    finalized = true;
    free(address);
  }
  static native void free(int address);
}
```

Finalizers are good for one thing.

Logging warnings

The alternative

An API-based approach:

```
public class WeakReference<T> {
  public WeakReference(T referent) {
     ...
  }
  public WeakReference(T referent,
                       ReferenceQueue<? super T> q) {
     ...
  }
  public T get() {
     ...
  }
  ...
}
```

What is a finalizer?

```
public class Button {
  private final List<WeakReference<Listener>> listeners
      = new ArrayList<WeakReference<Listener>>();
  public void add(Listener l) {
    listeners.add(new WeakReference<Listener>(l));
  }
  public void click() {
    Iterator<WeakReference<Listener>> i
        = listeners.iterator();
    while (i.hasNext()) {
      Listener l = i.next().get();
      if (l == null) i.remove();
      else l.onClick();
    }
  }
  public interface Listener {
    void onClick();
  }
}
```

The alternative

```
public class ReferenceQueue<T> {
  public T poll() {
    ...
  }
  public T remove() {
    ...
  }
  public T remove(long timeout) {
    ...
  }
}
```

Reachability

- An object is *reachable* if a live thread can access it.
- Examples of heap roots:
  - System classes (which have static fields)
  - Thread stacks
  - In-flight exceptions
  - JNI global references
  - The finalizer queue
  - The interned String pool
  - etc. (VM-dependent)

Making maps

```
public class BytecodeCache {
  final static Map<Class<?>, byte[]> cache = new MapMaker()
      .weakKeys()
      .softValues()
      .makeComputingMap(new Function<Class<?>, byte[]>() {
        public byte[] apply(Class<?> clazz) {
          ...
        }
      });

  public static byte[] bytesFor(Class<?> clazz) {
    return cache.get(clazz);
  }
}
```

Dante's Heap - The Levels of Reachability

- Strong
- Soft
- Weak
- Finalizer
- Phantom, JNI weak
- Unreachable

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Dante's Heap - The Levels of Reachability

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- Soft
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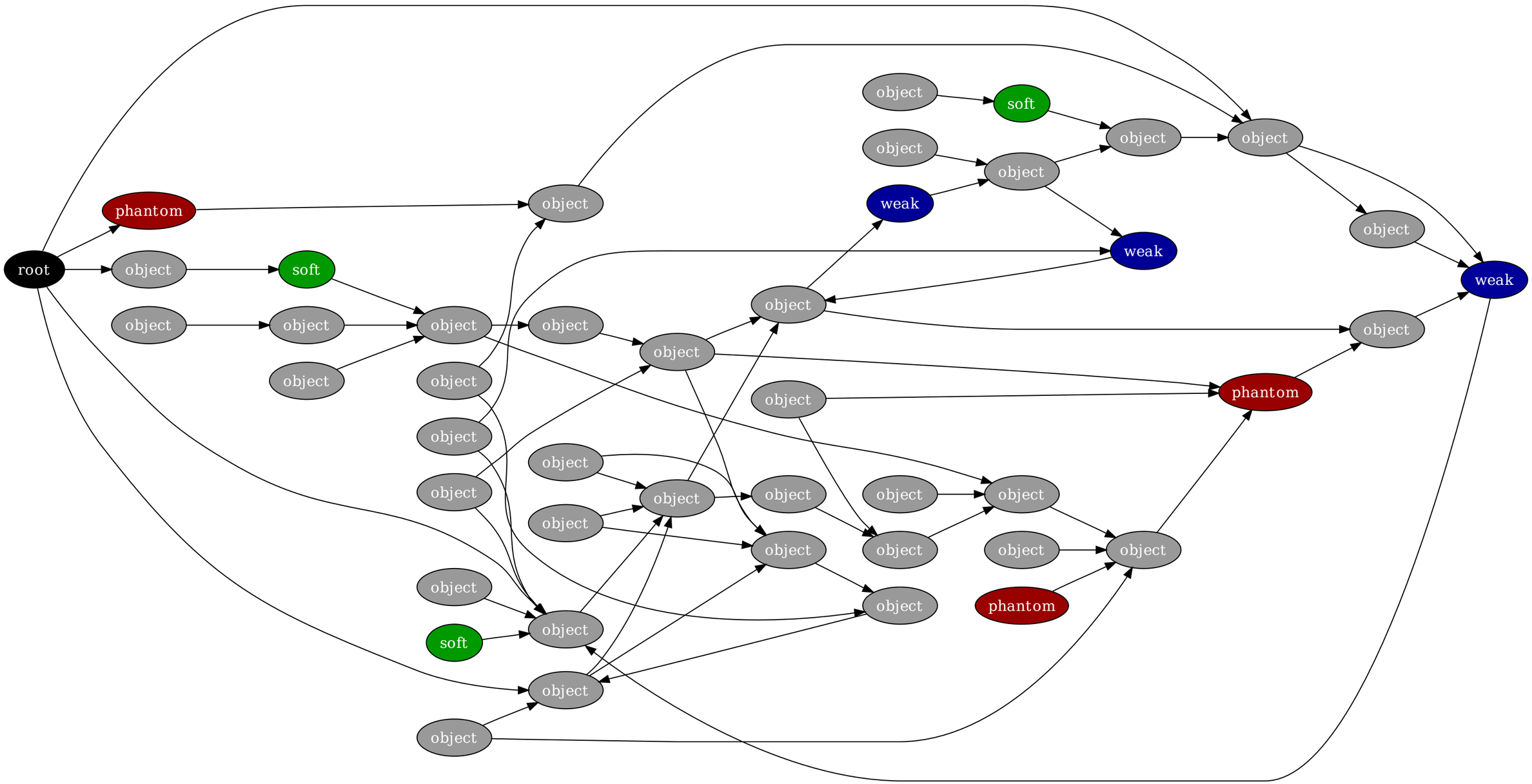
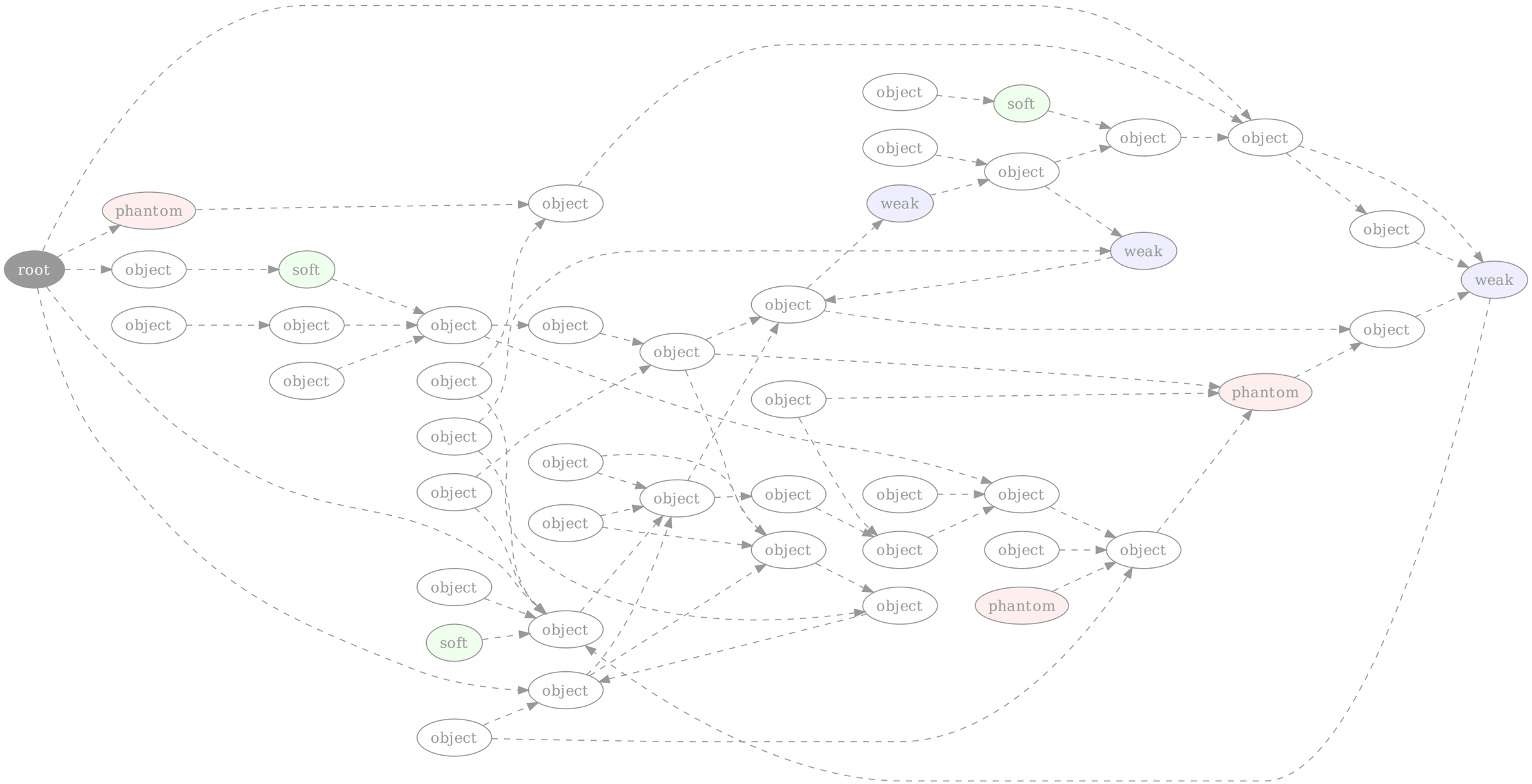
- Finalizer
- Phantom, JNI weak
- **Unreachable**

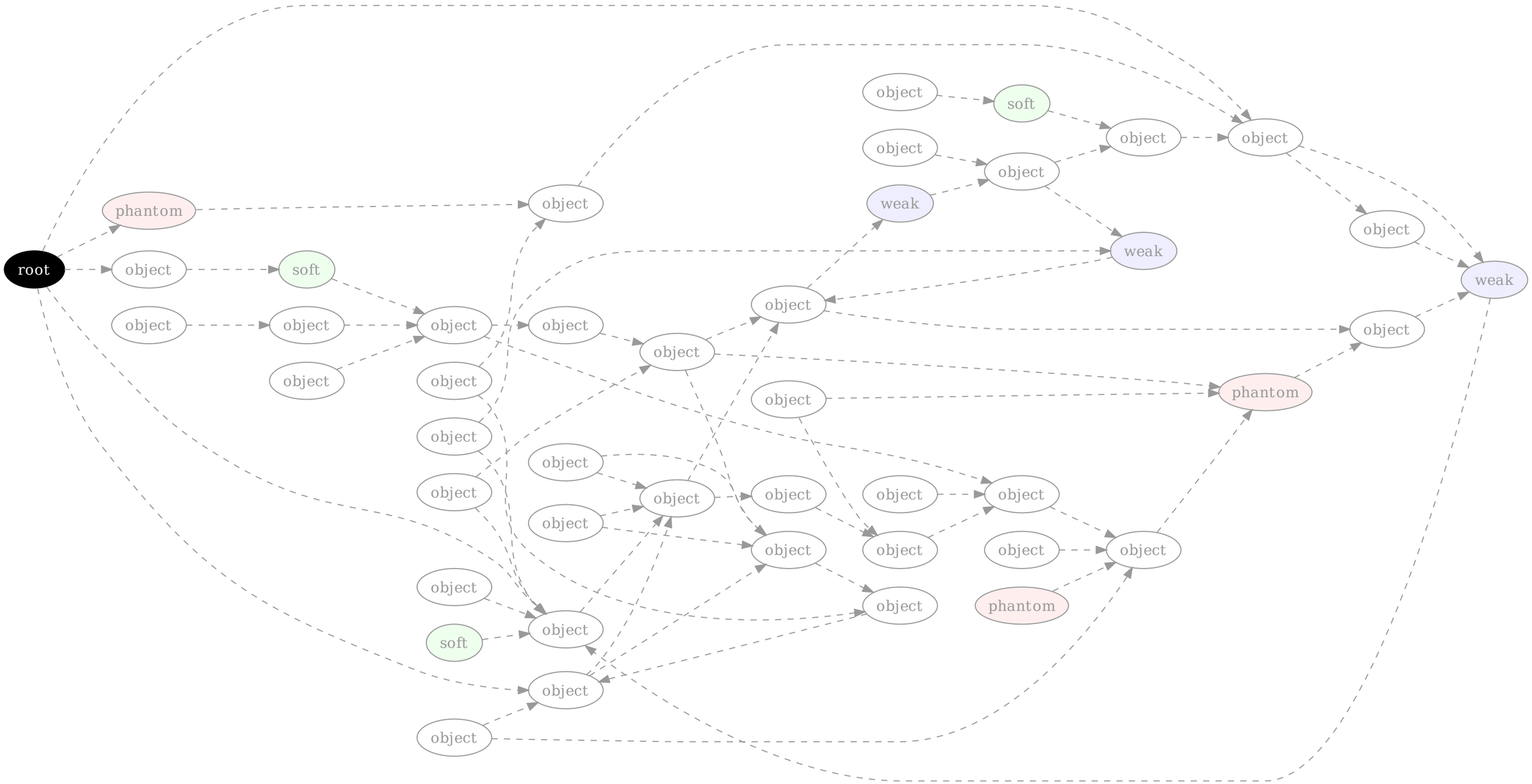
Let's mark and sweep a heap!



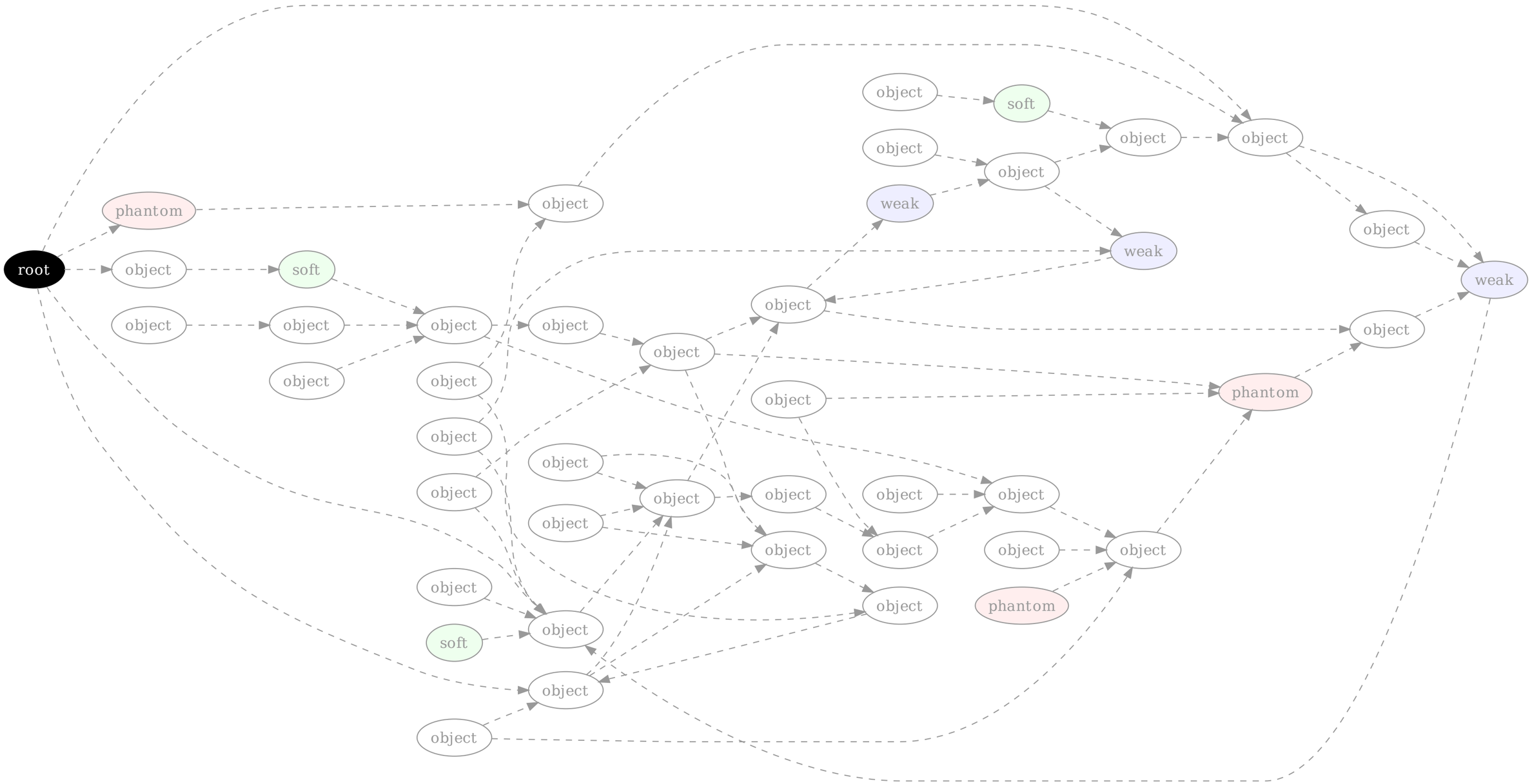
No objects are marked at first.



1. Start at a root.



2. Trace and mark strongly-referenced objects.



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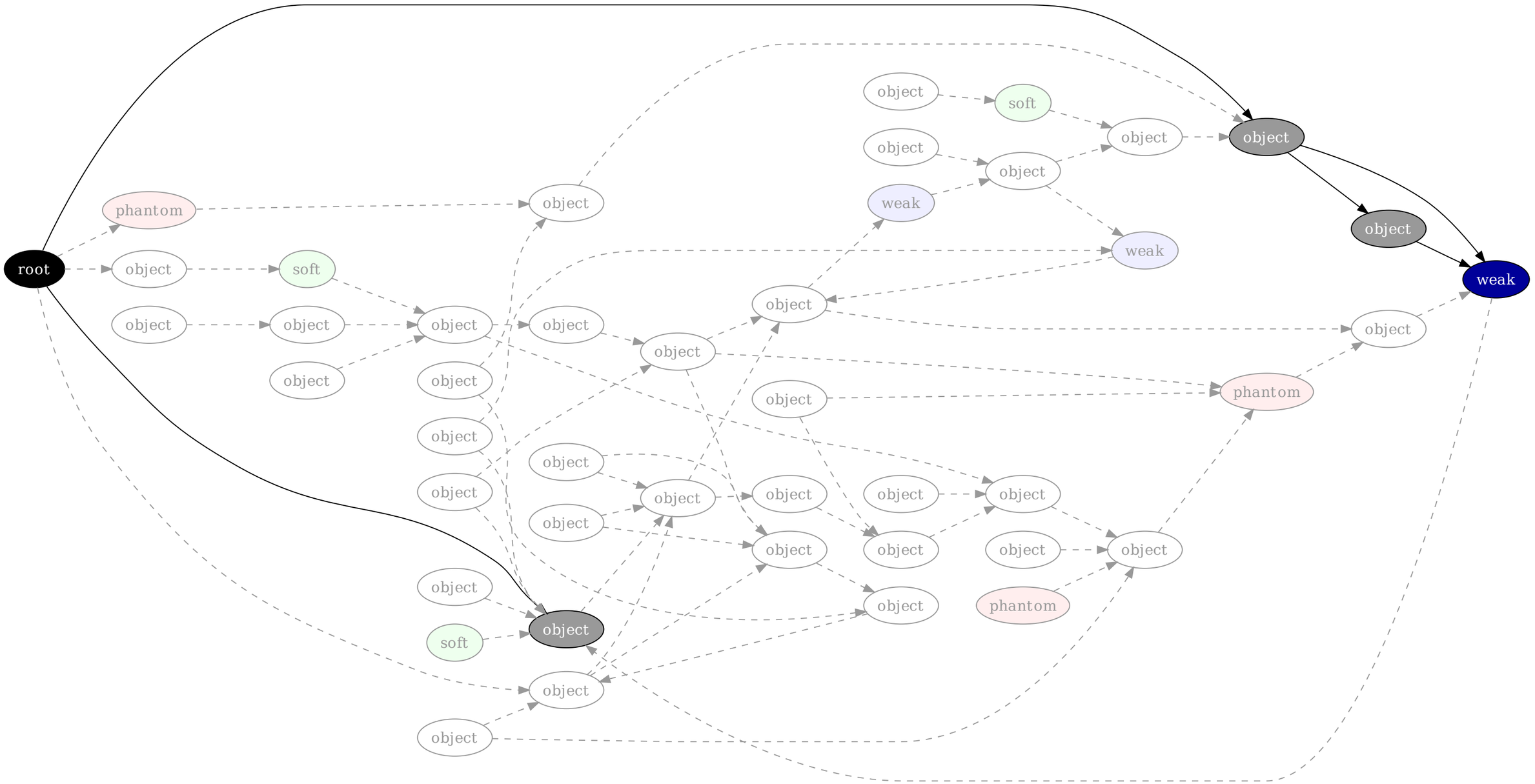

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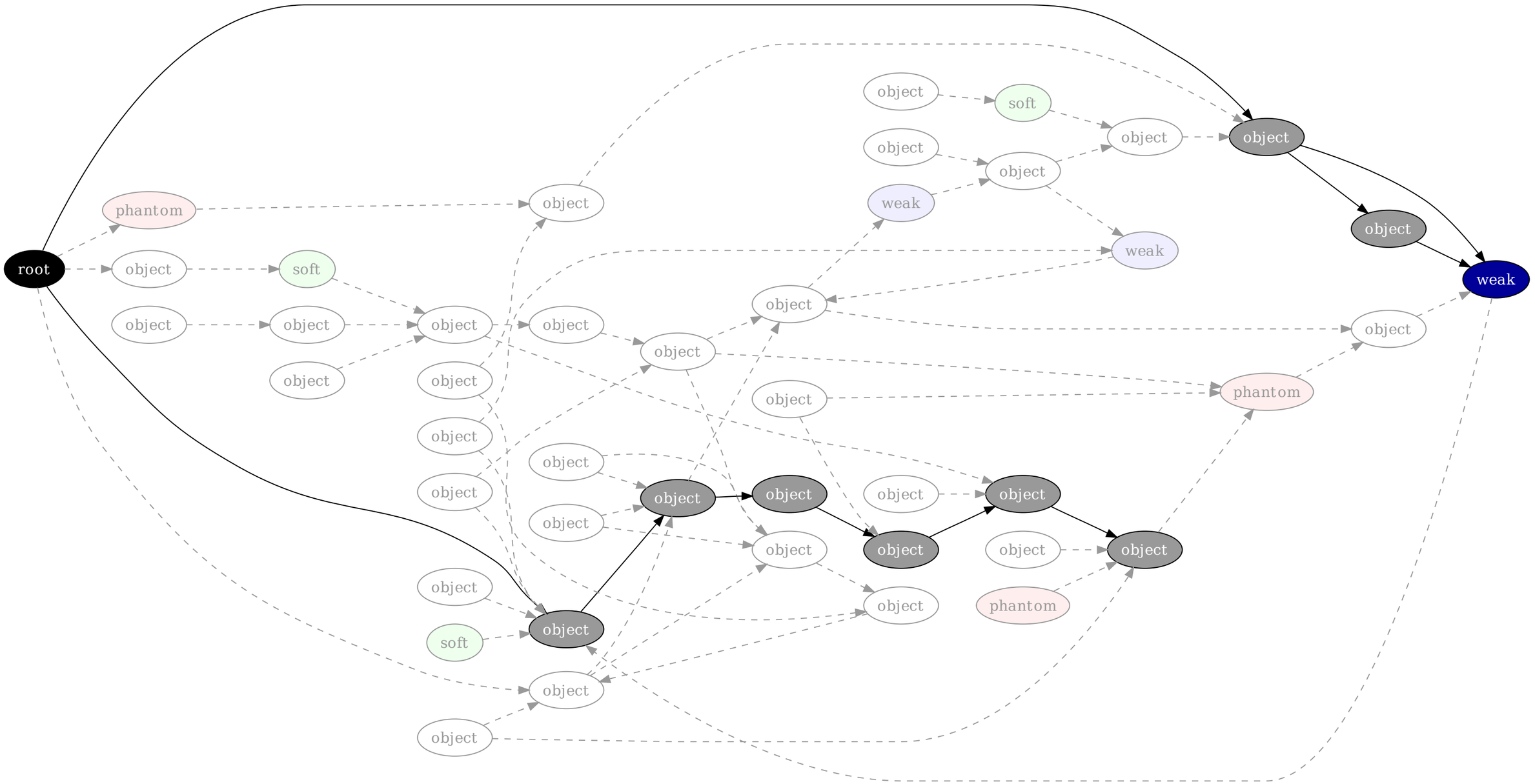

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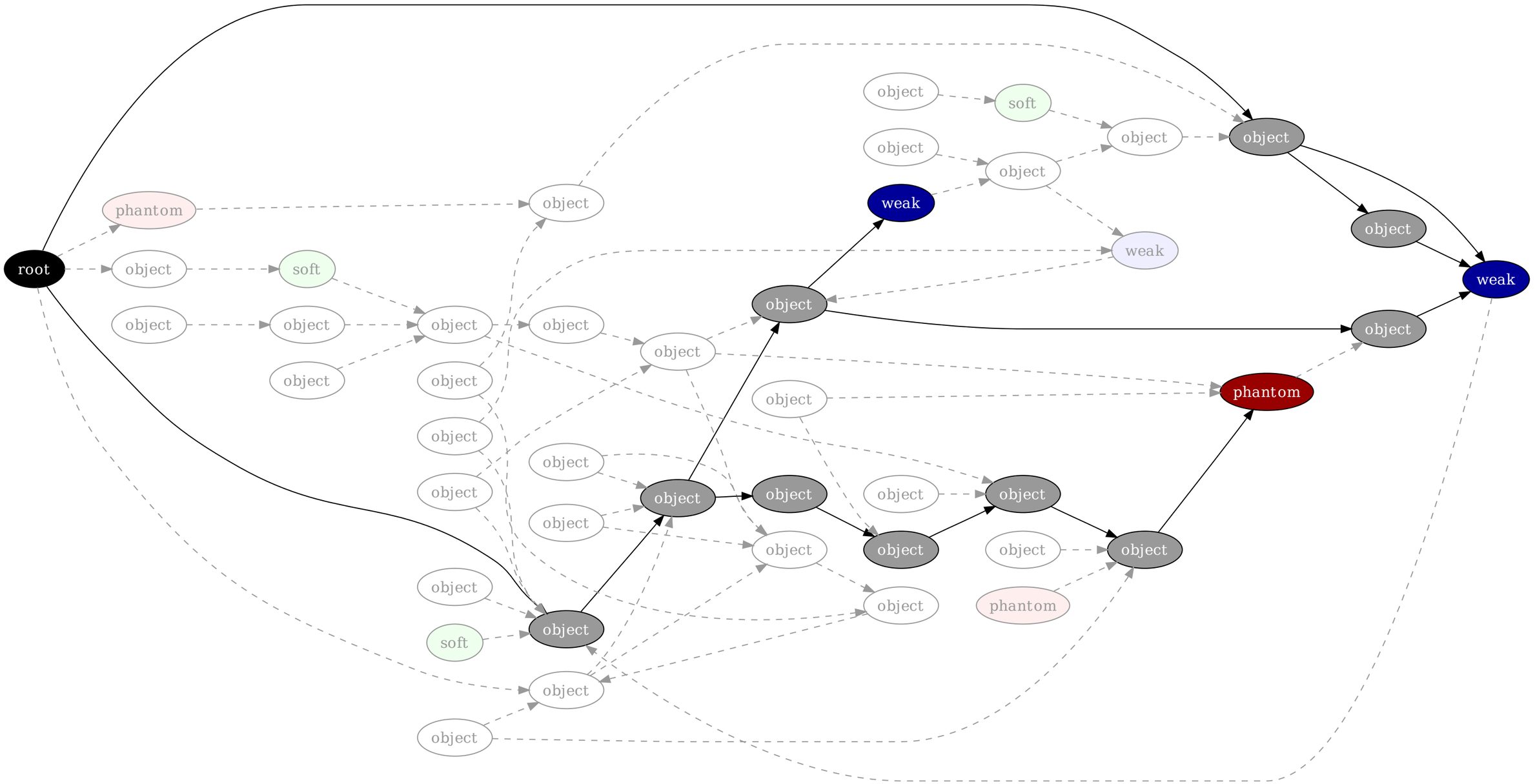

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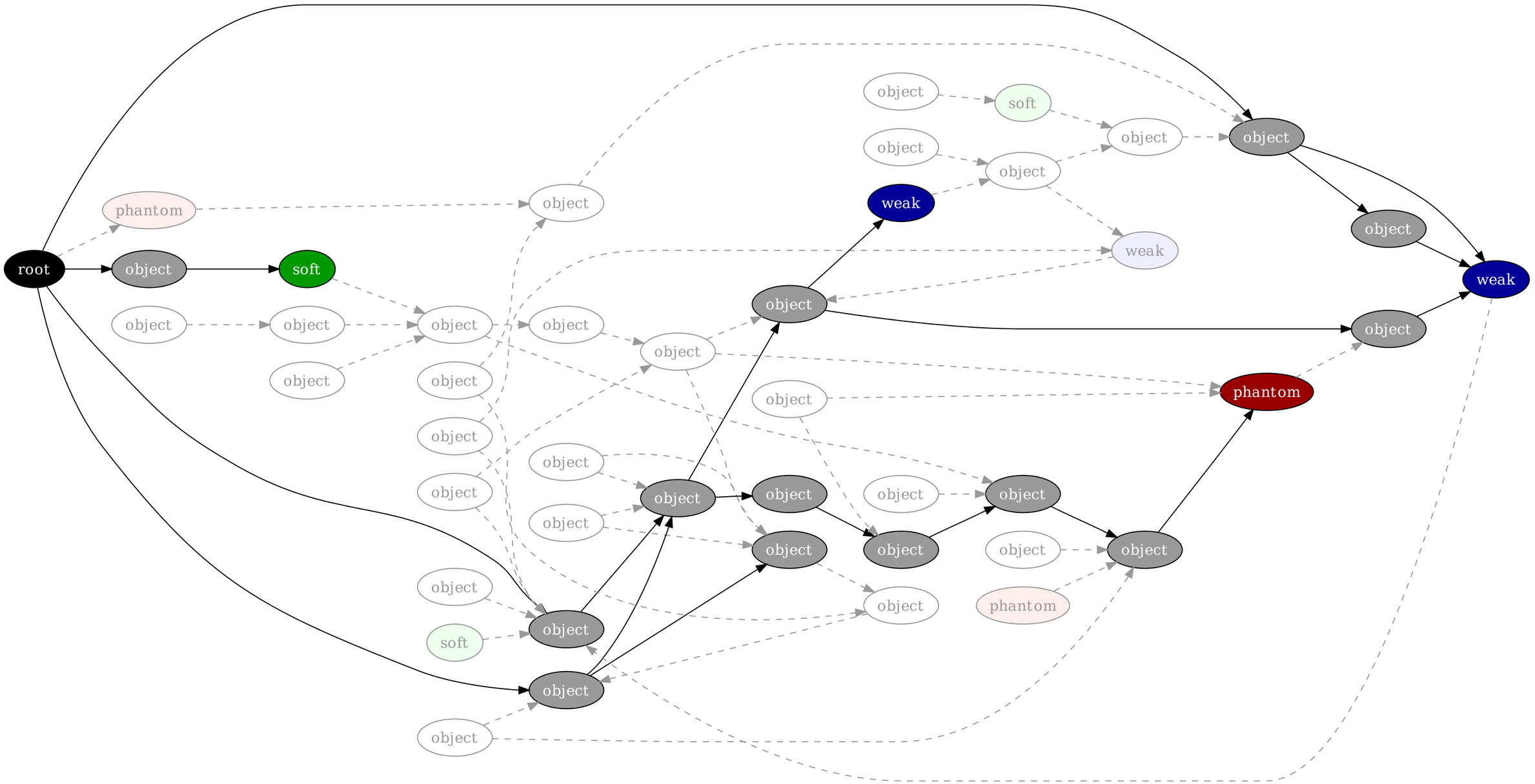

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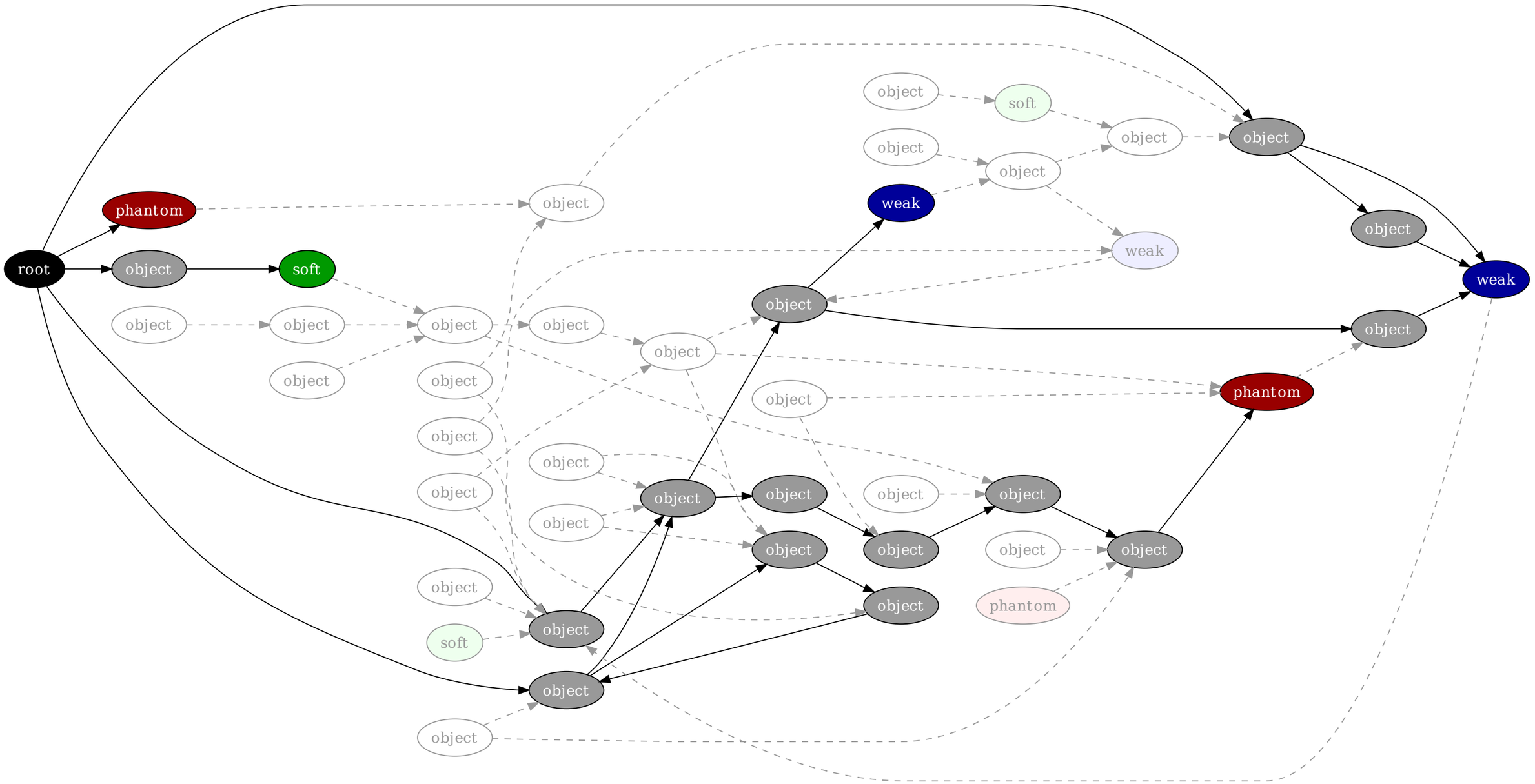
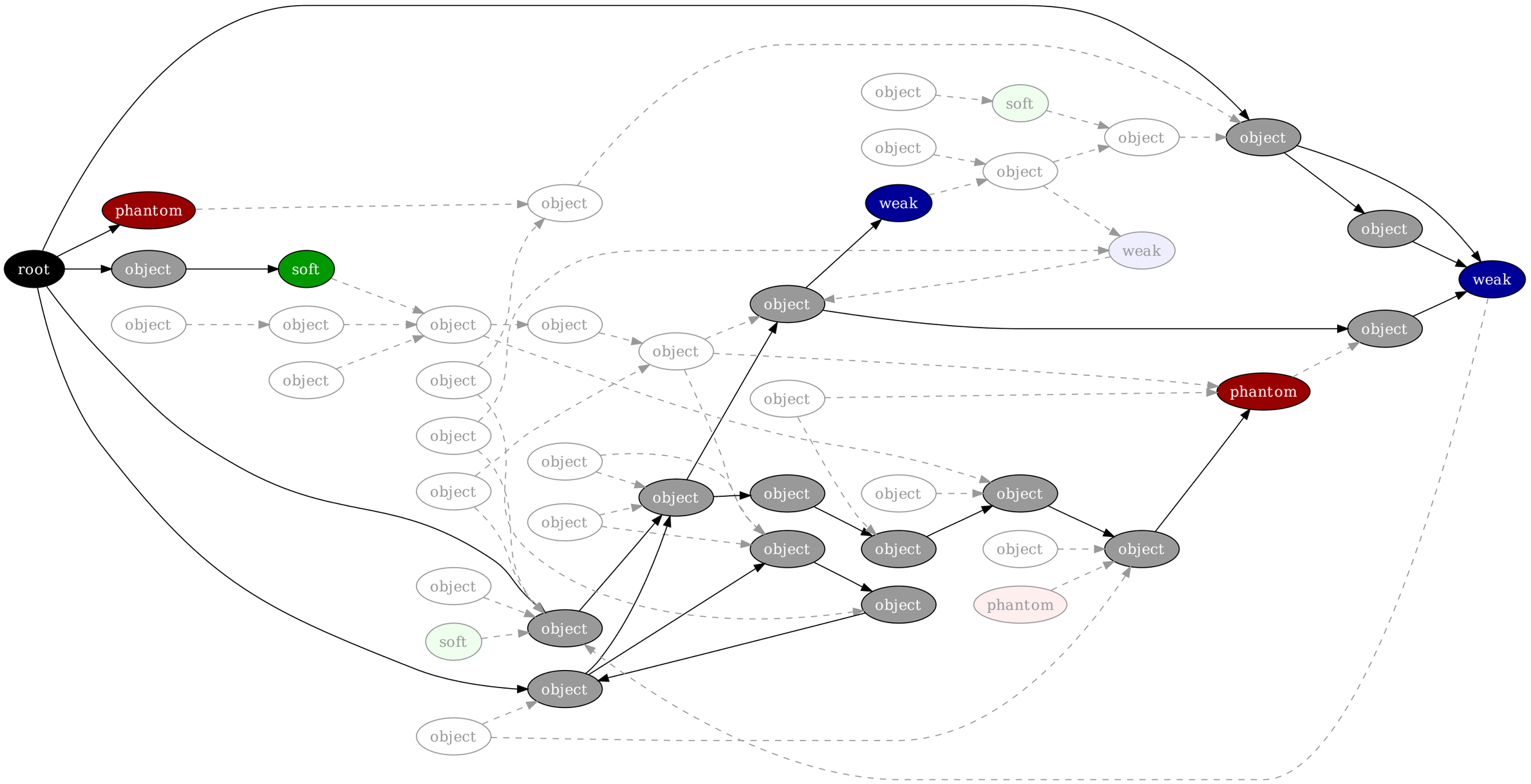
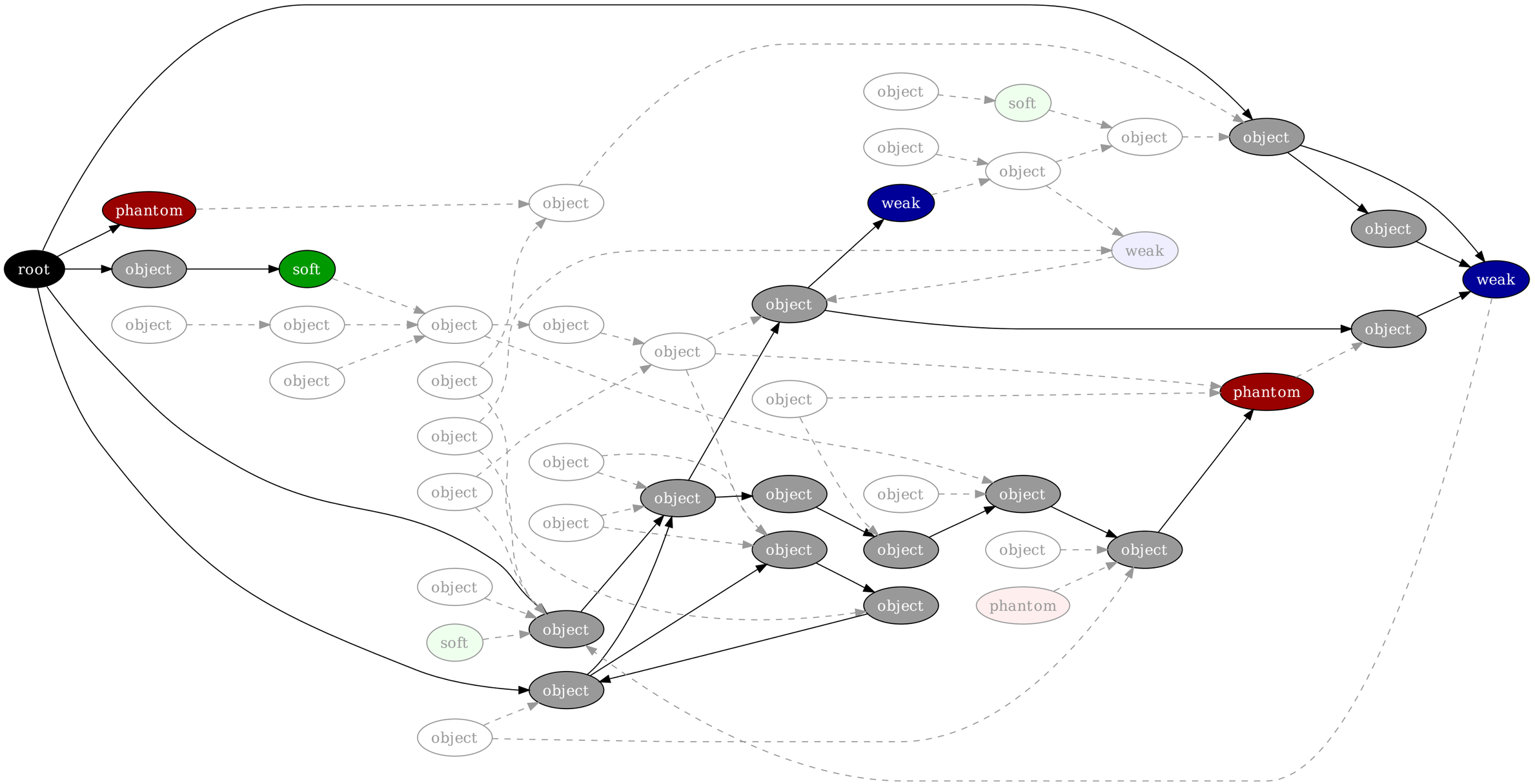


3. Optionally clear soft references.



4. Trace and mark softly-referenced objects.



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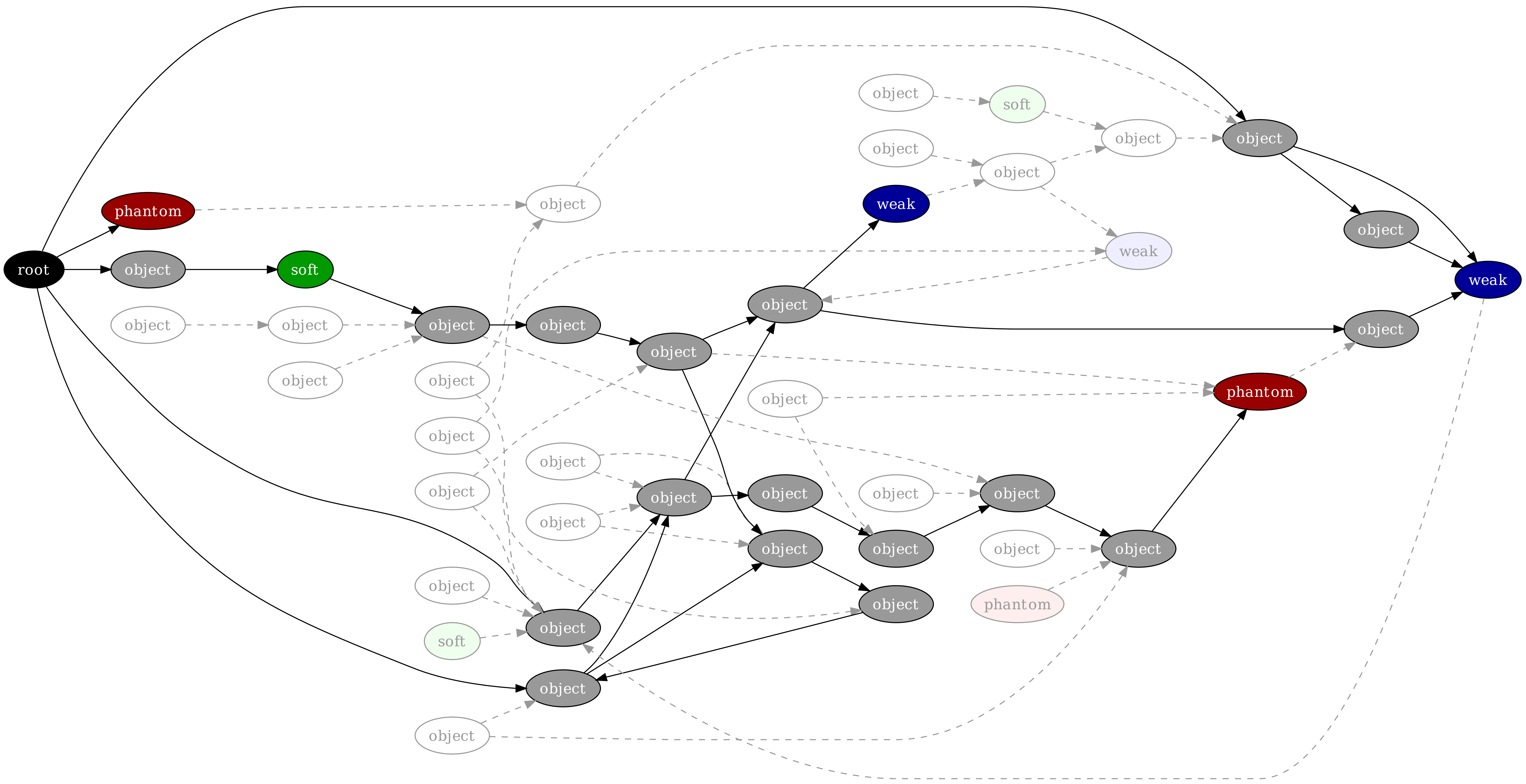

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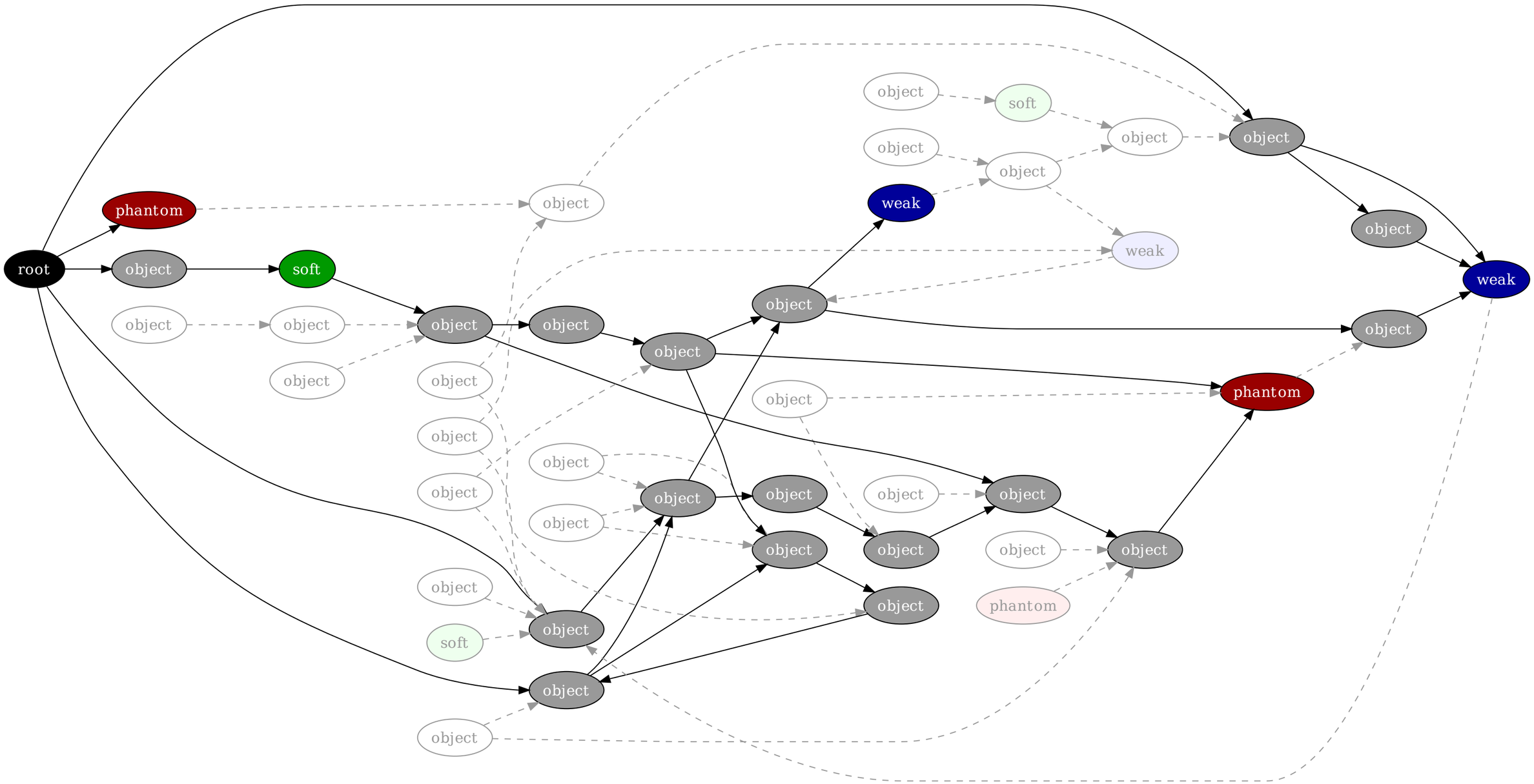

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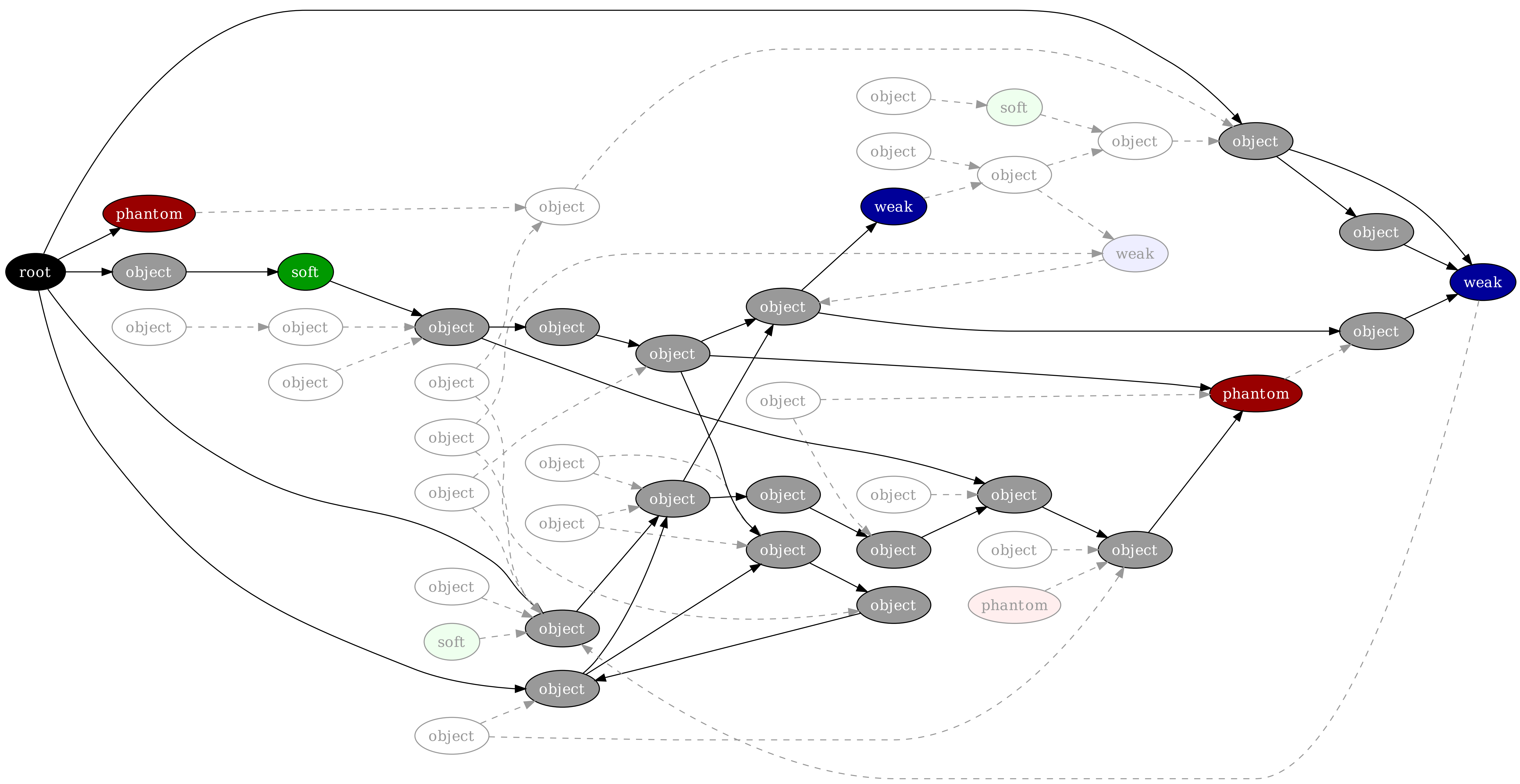
5. Clear weak references.



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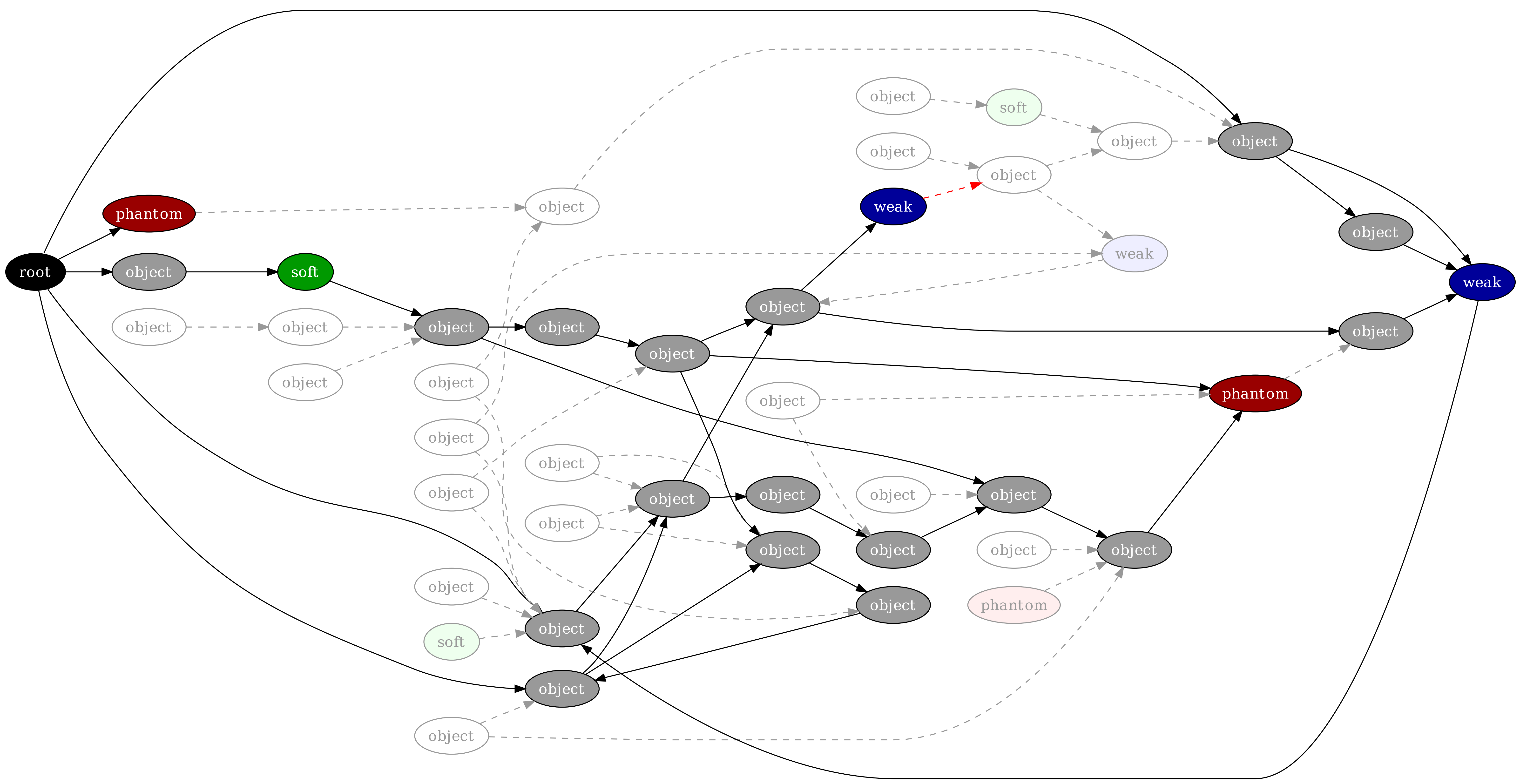

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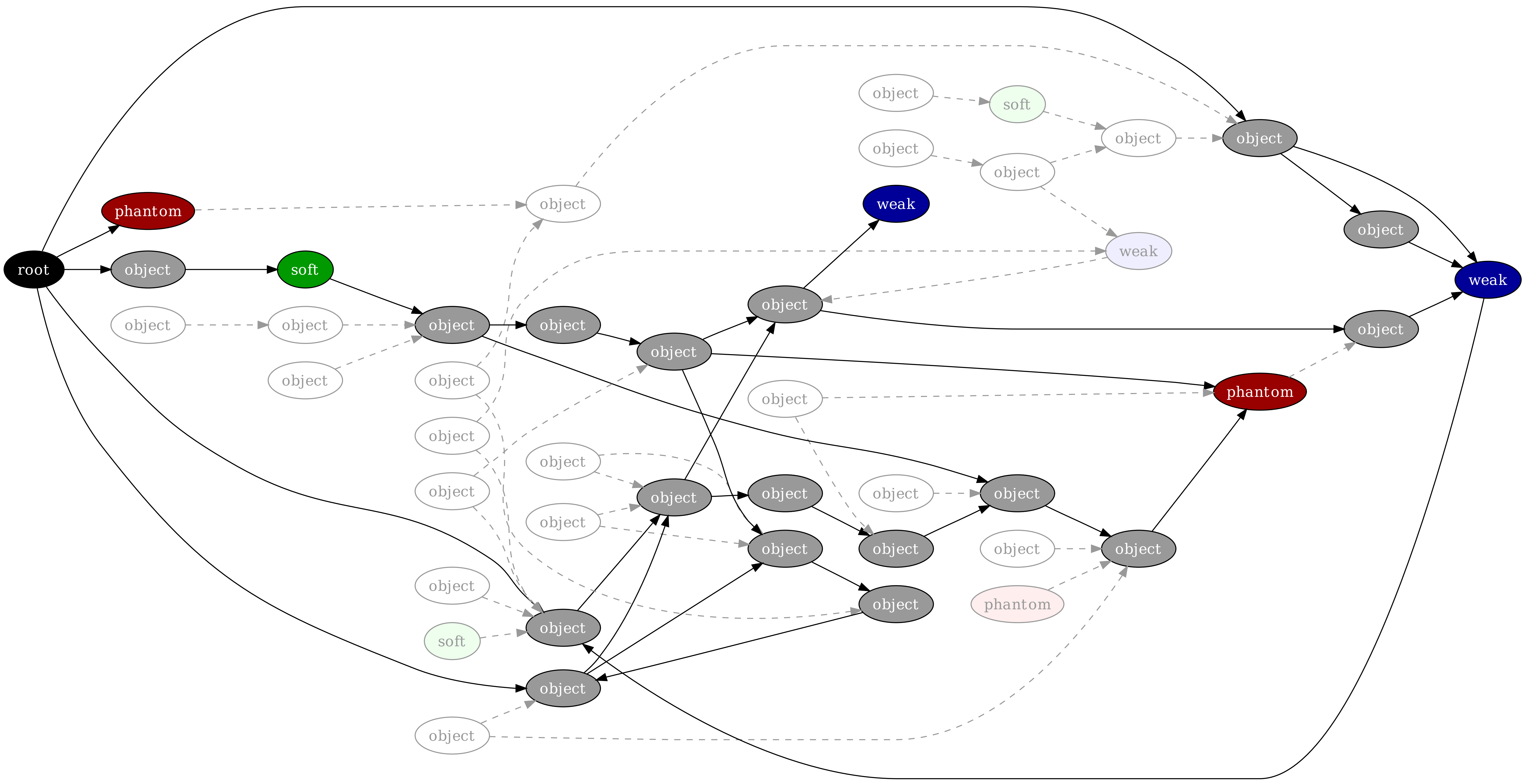
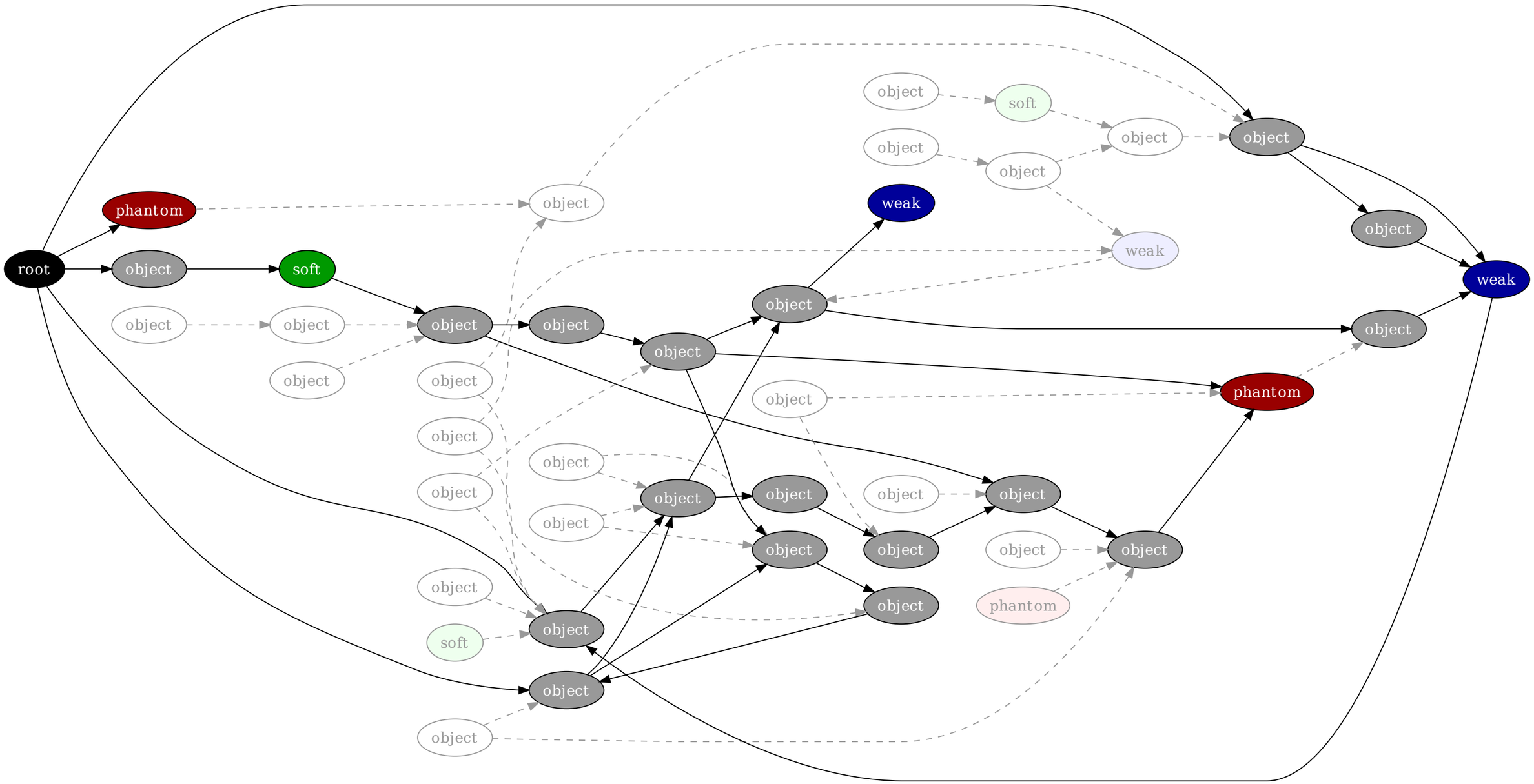


6. Enqueue finalizable objects.



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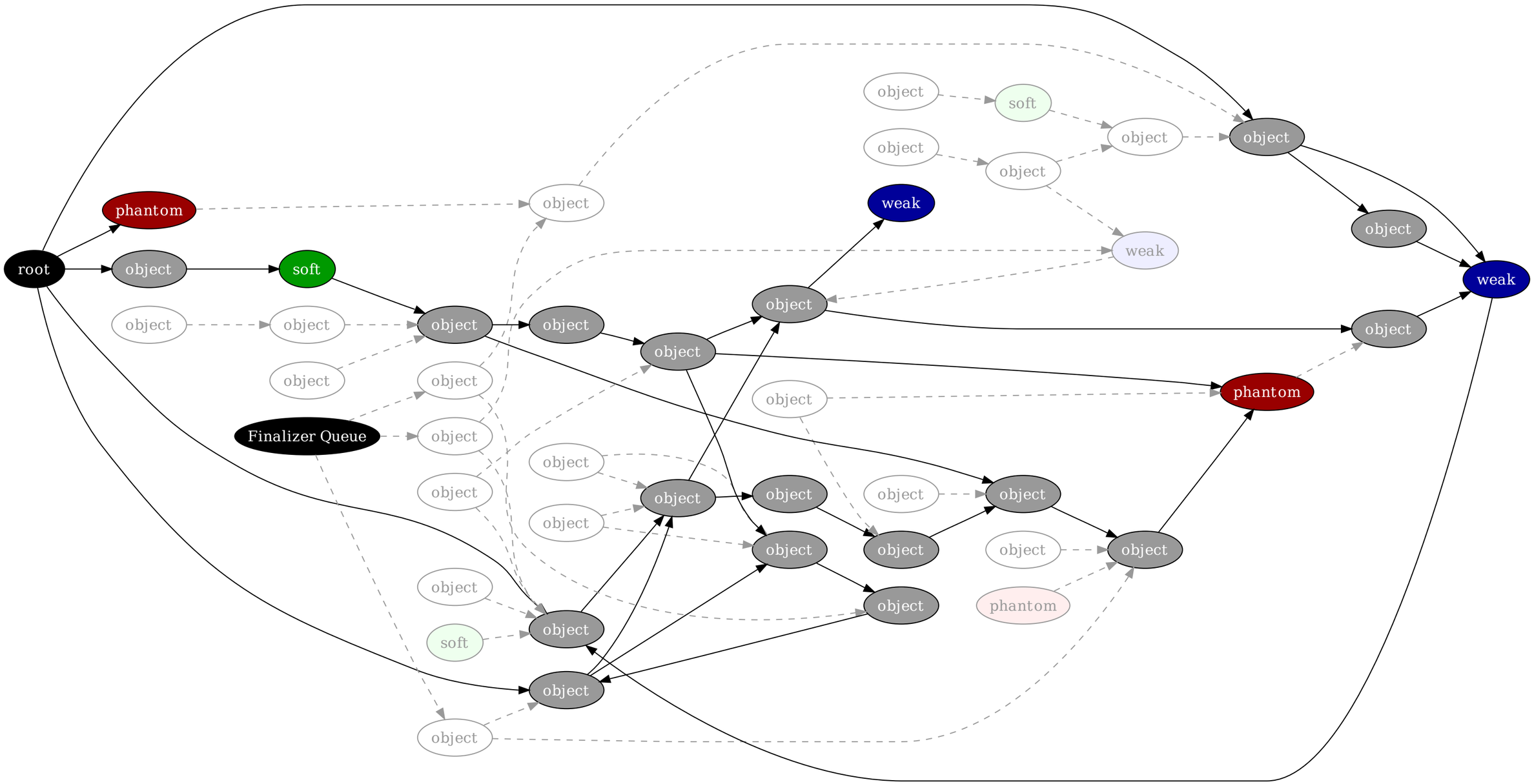
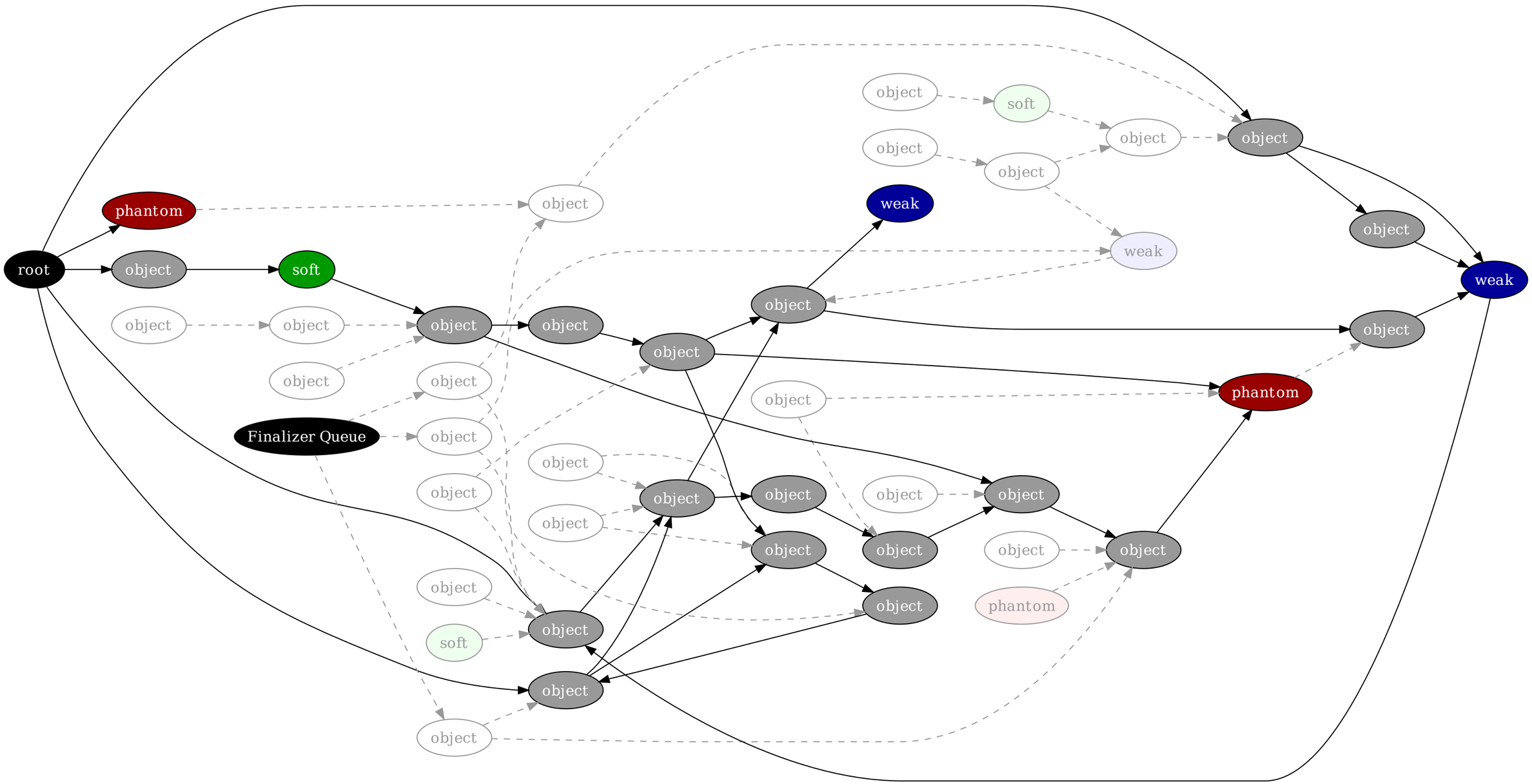


7. Repeat steps 1 through 5 for the queue.



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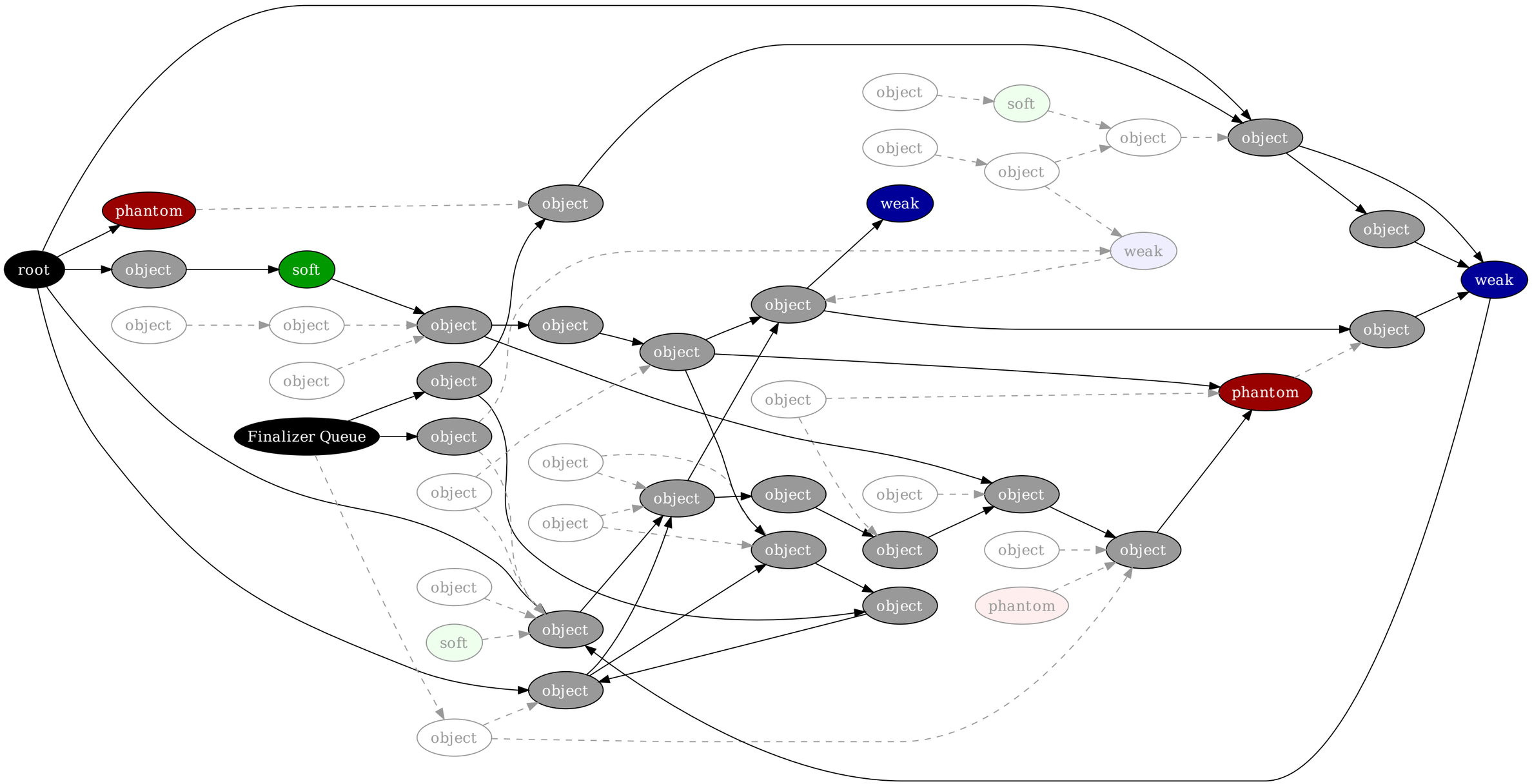

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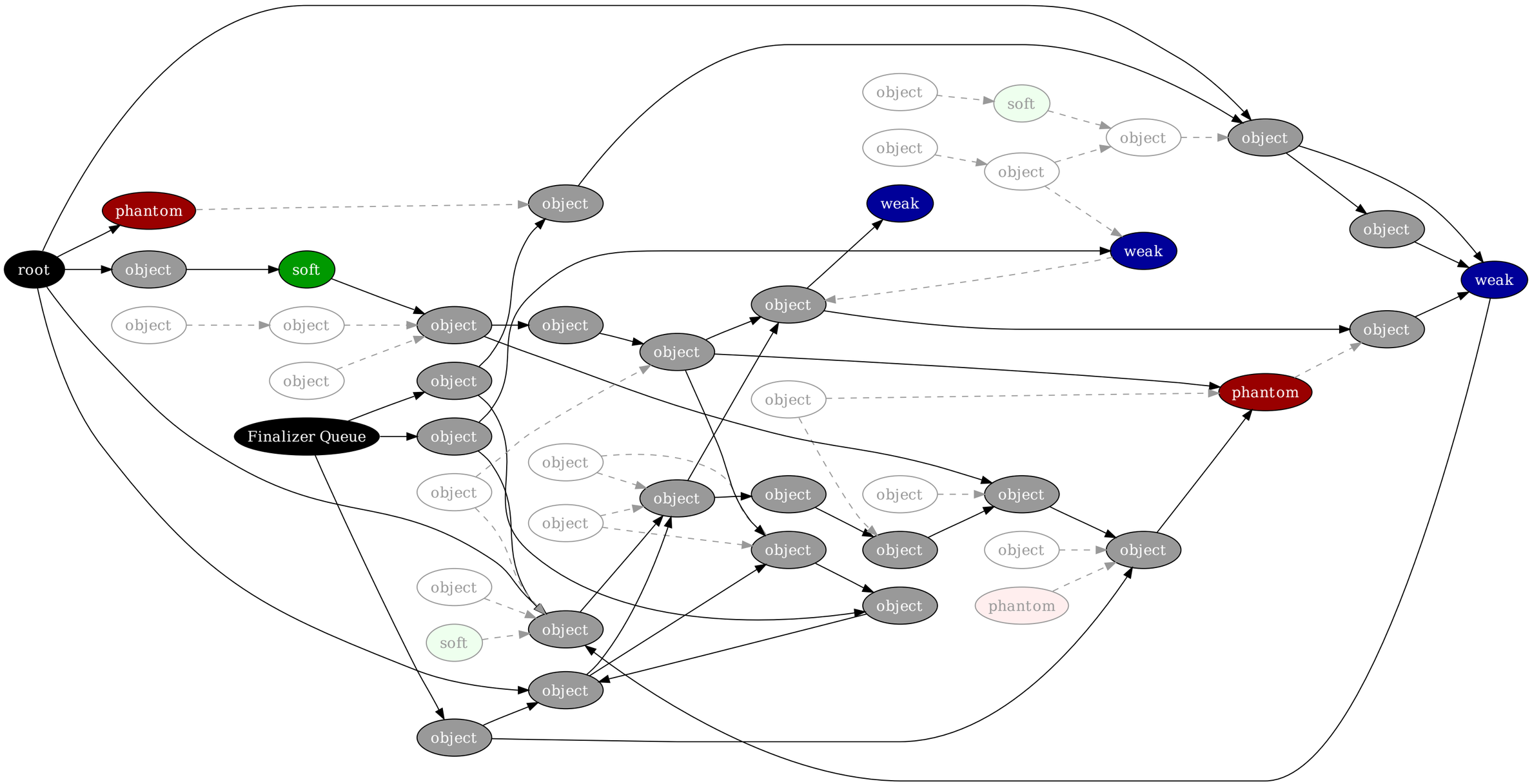

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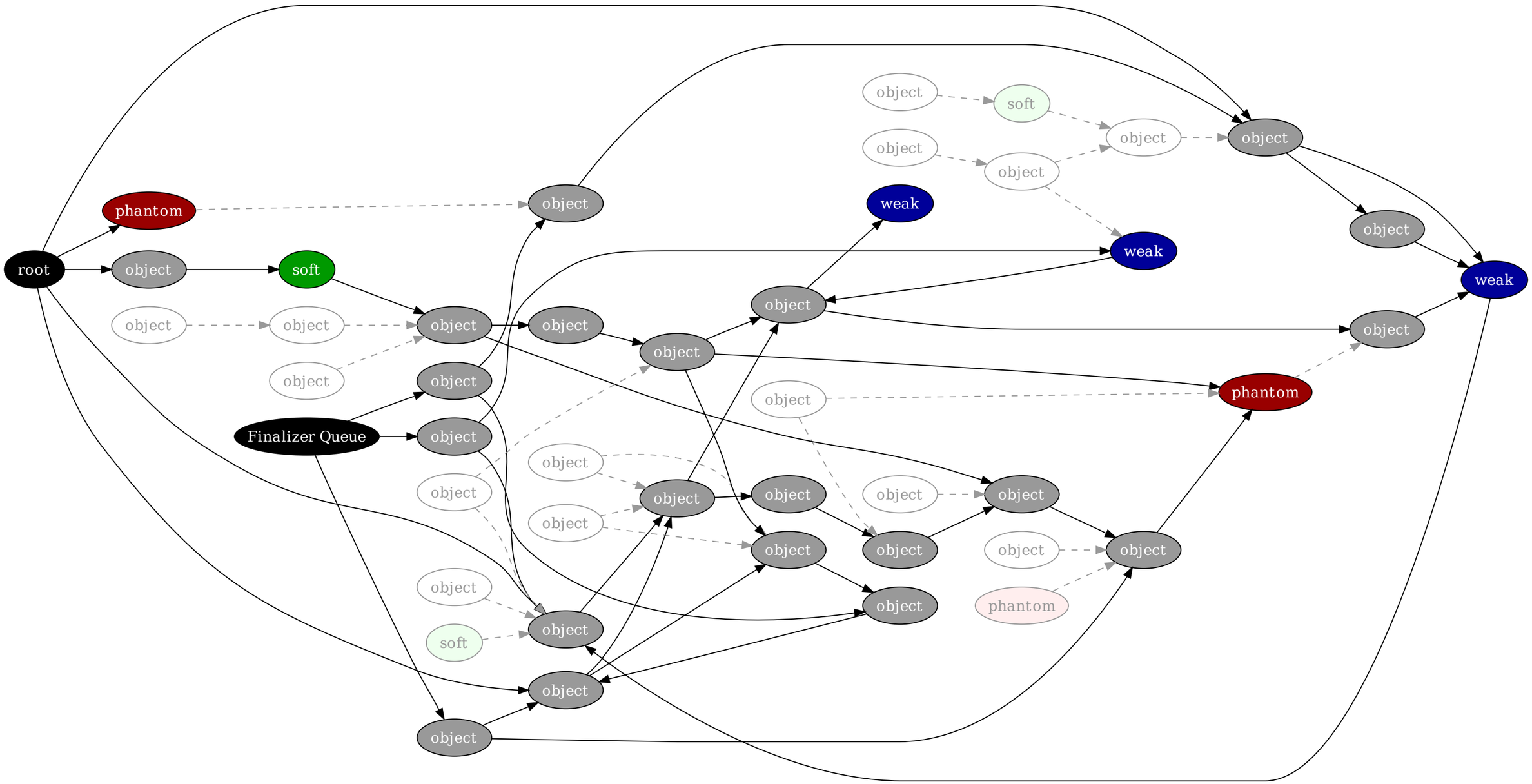
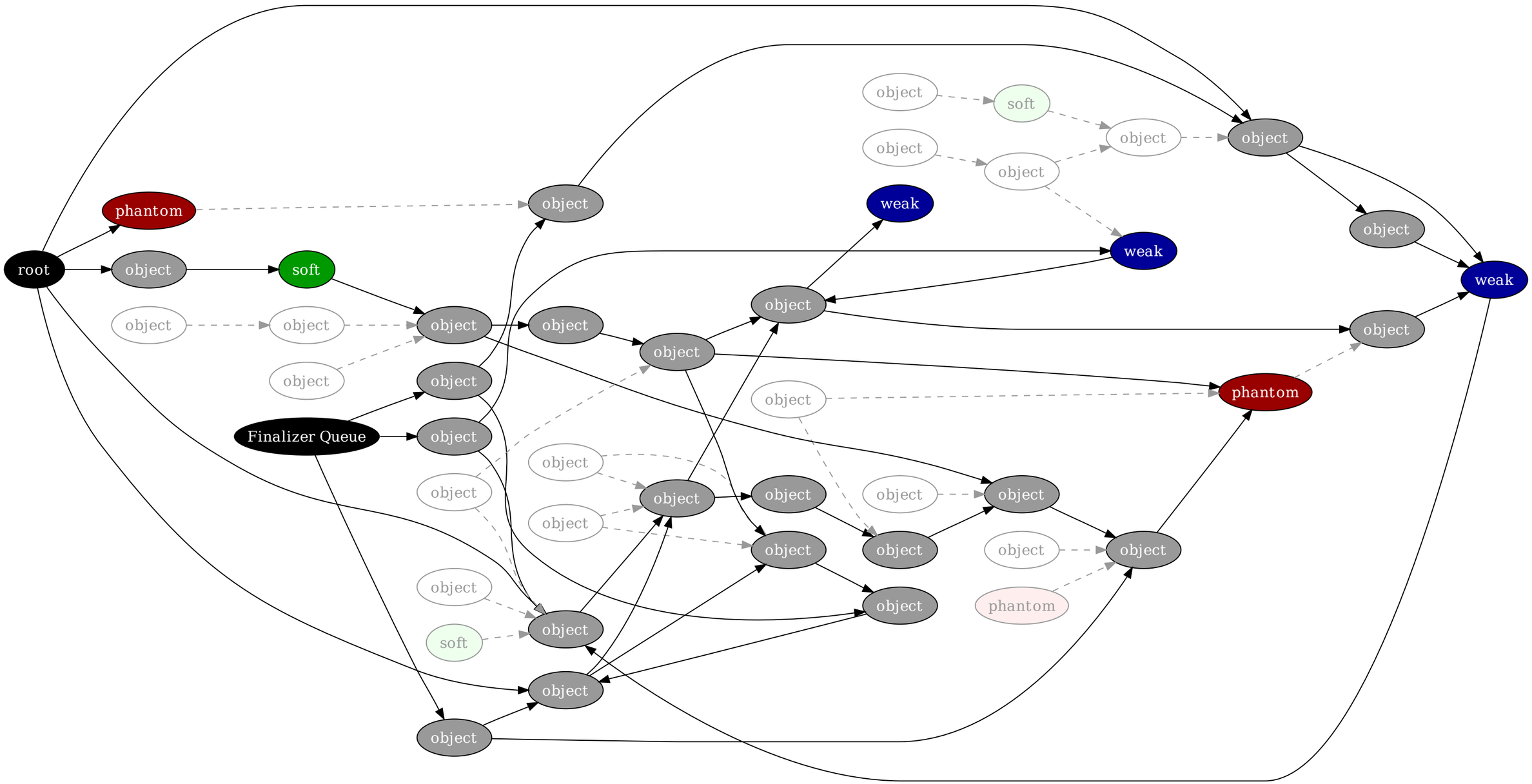


8. Possibly enqueue phantom references.



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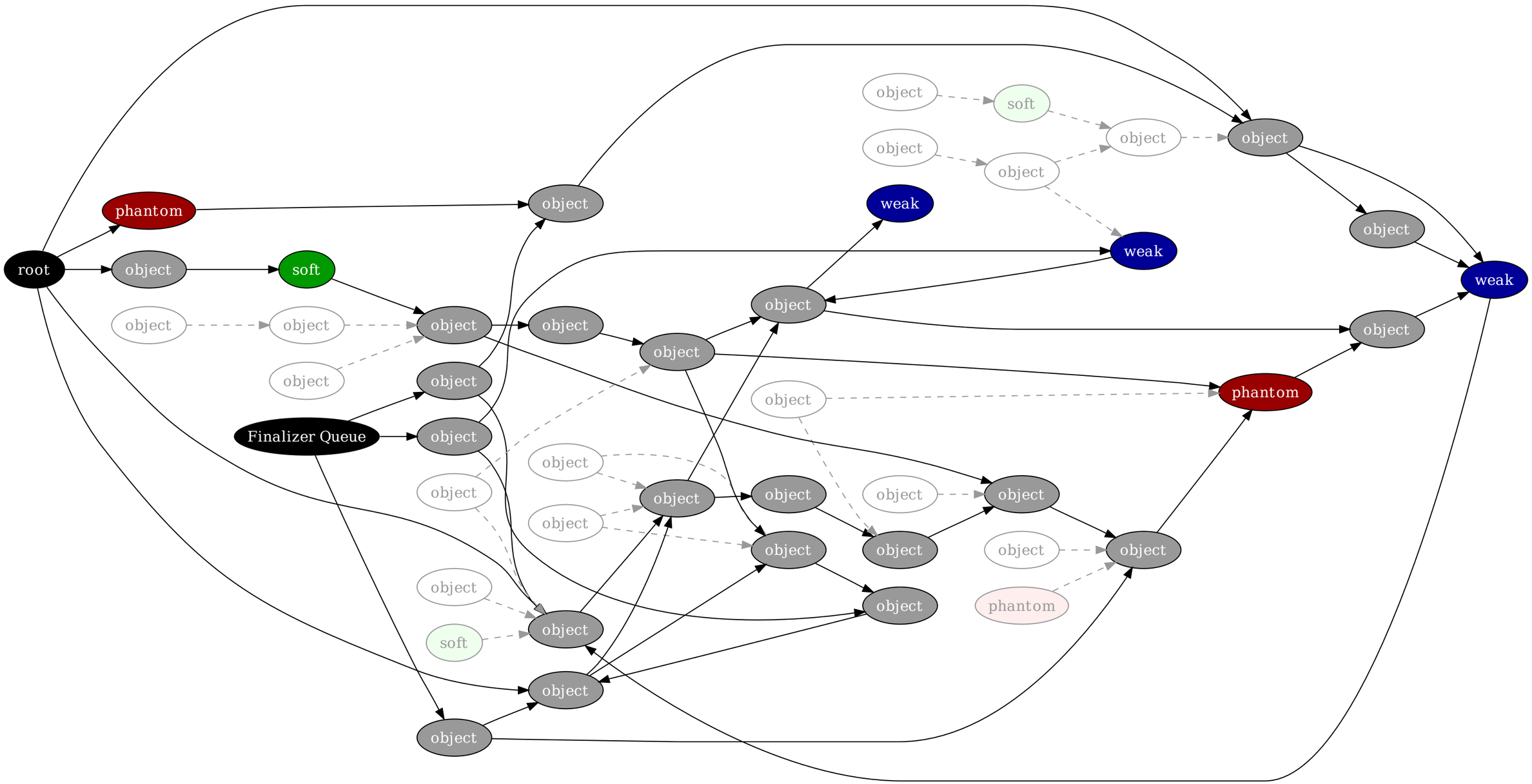
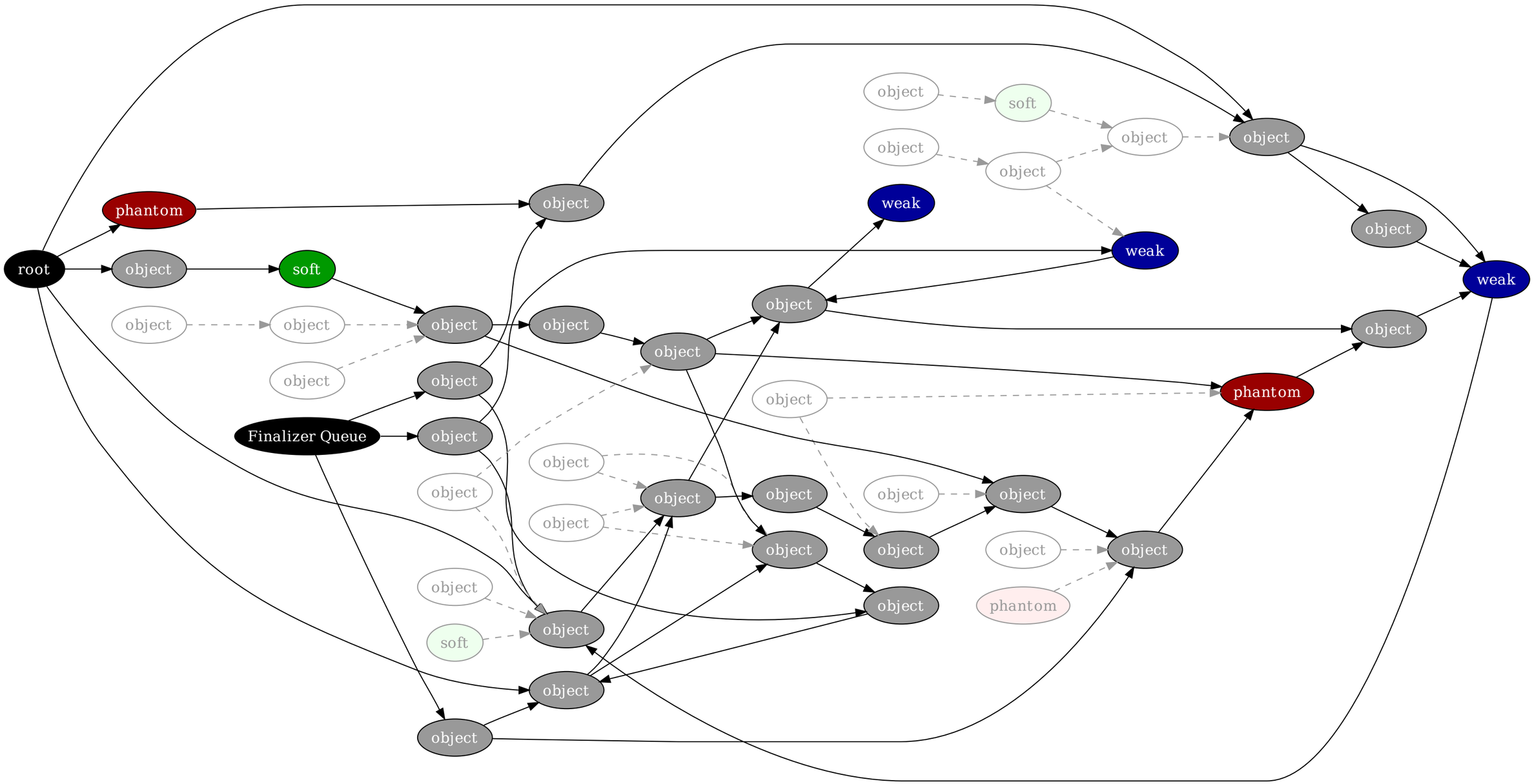


9. The remaining objects are dead.



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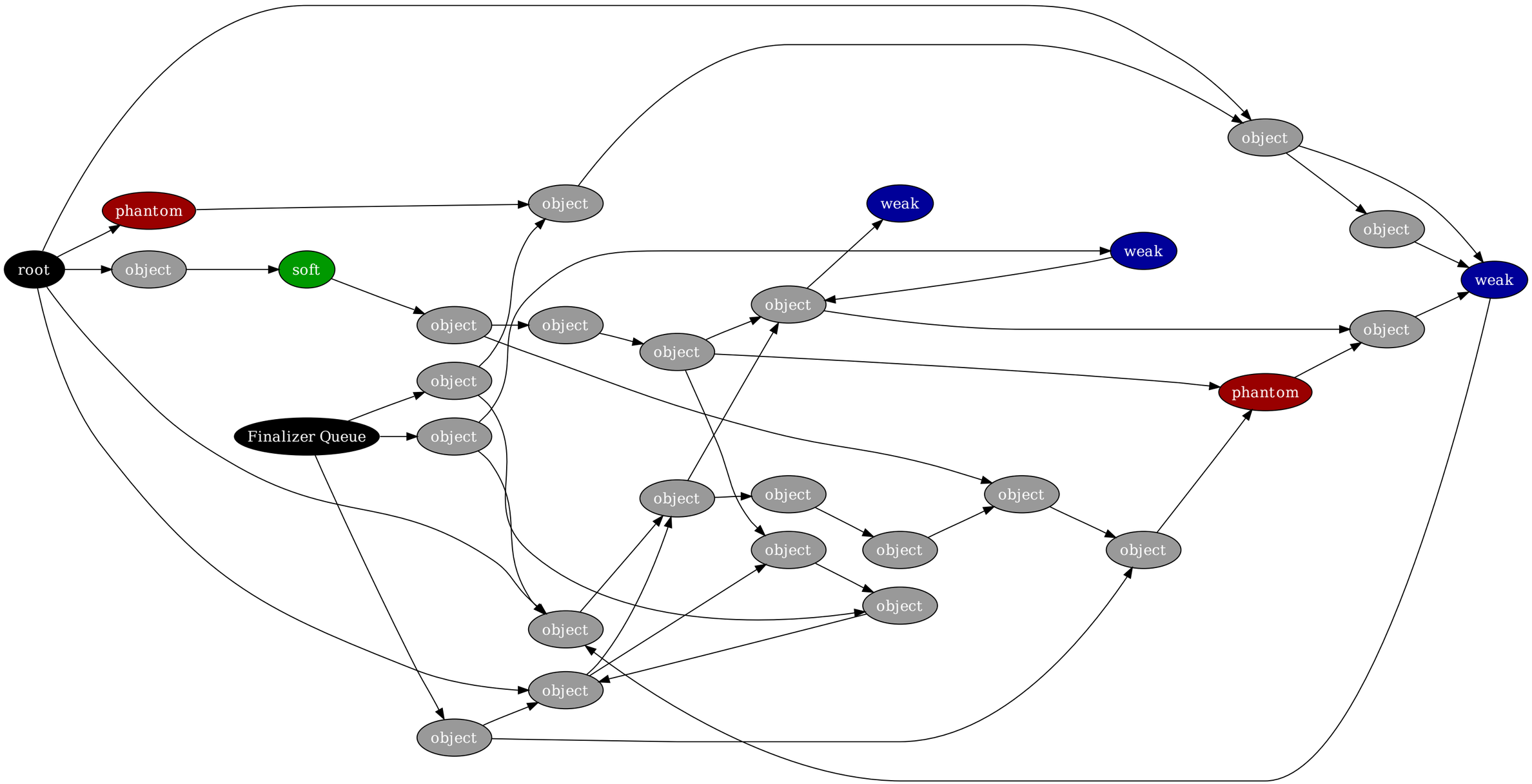
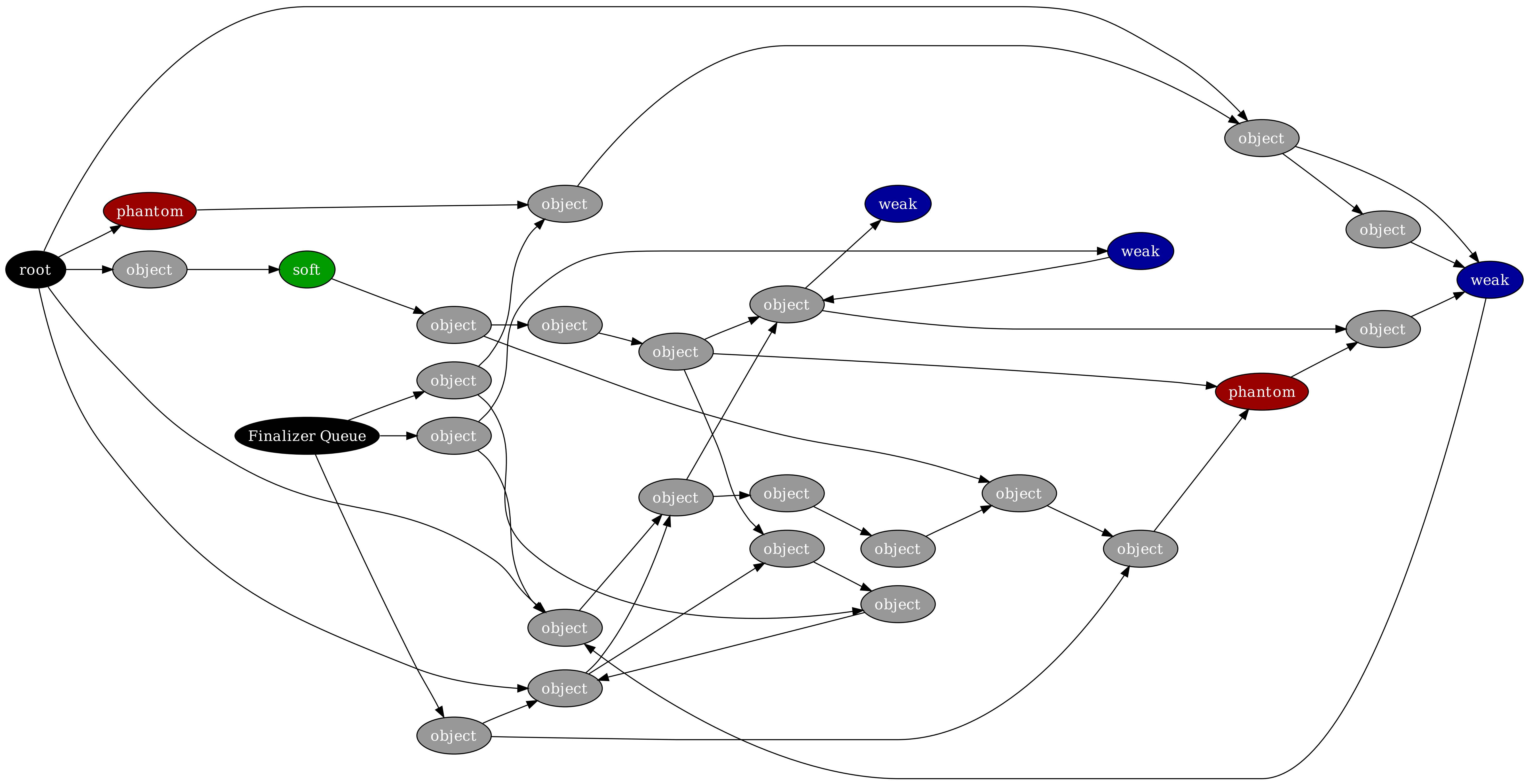


10. Repeat.


root
phantom
object
soft
object
object
object
weak
weak
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object
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phantom
Finalizer Queue
object
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object

Recap

1. Start at a root.

2. Trace and mark strongly-referenced objects.

3. Optionally clear soft references.

4. Trace and mark softly-referenced objects.

5. Clear weak references.

6. Enqueue finalizable objects.

7. Repeat steps 1 through 5 for the queue.

8. Possibly enqueue phantom references.

9. The remaining objects are dead.

10. Repeat.

Weak references aren't for caching!

- Many collectors will reclaim weak refs immediately.
- Use soft reference for caching, as intended:

“Virtual machine implementations are encouraged to bias against clearing recently-created or recently-used soft references.”

- The `SoftReference` documentation