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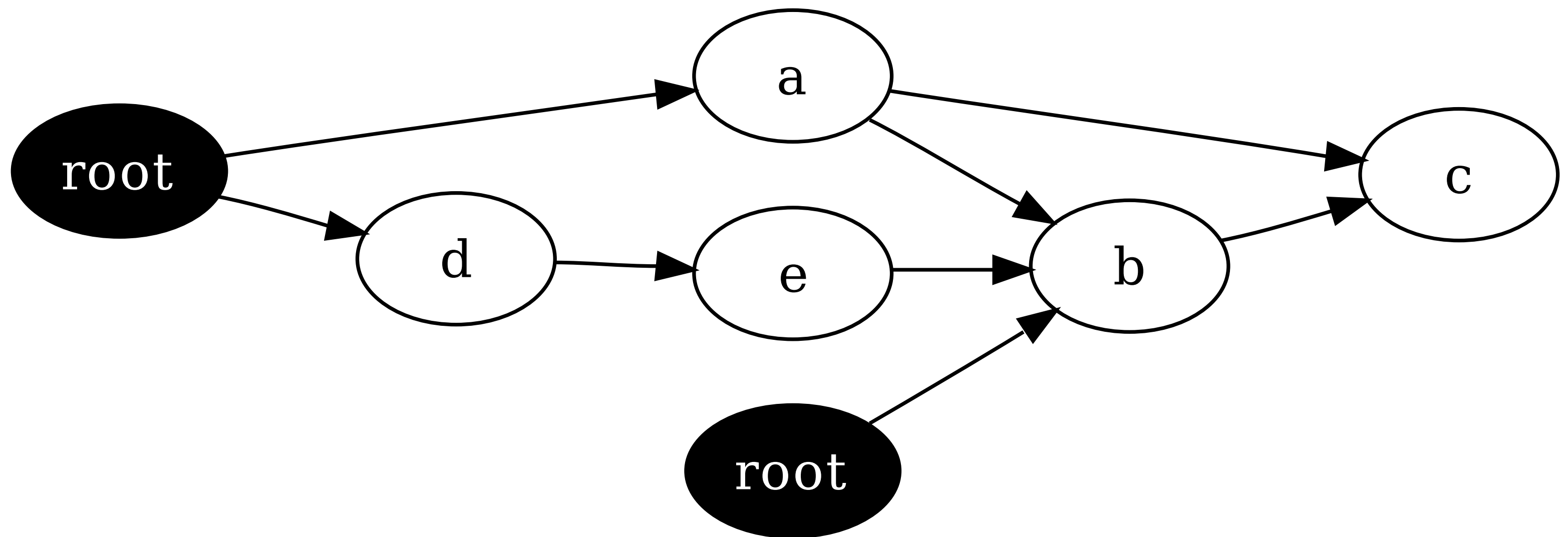
The Ghost in the Virtual Machine A Reference to References

Bob Lee
Google Inc.

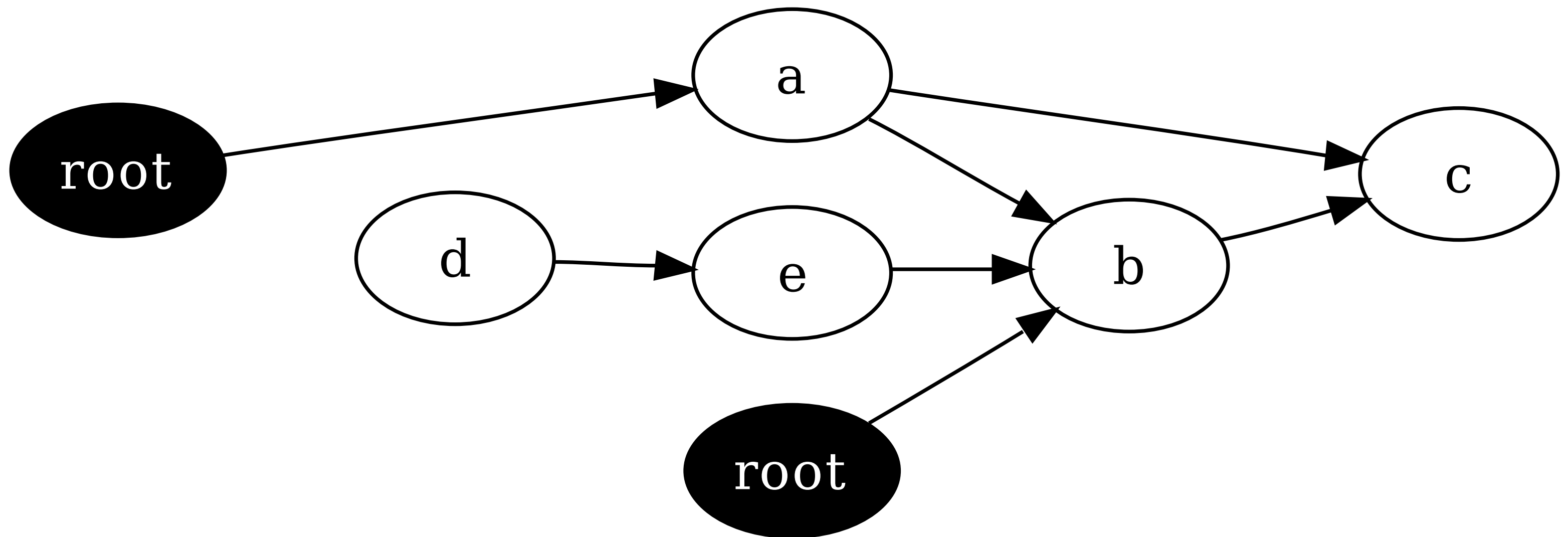
Goals

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

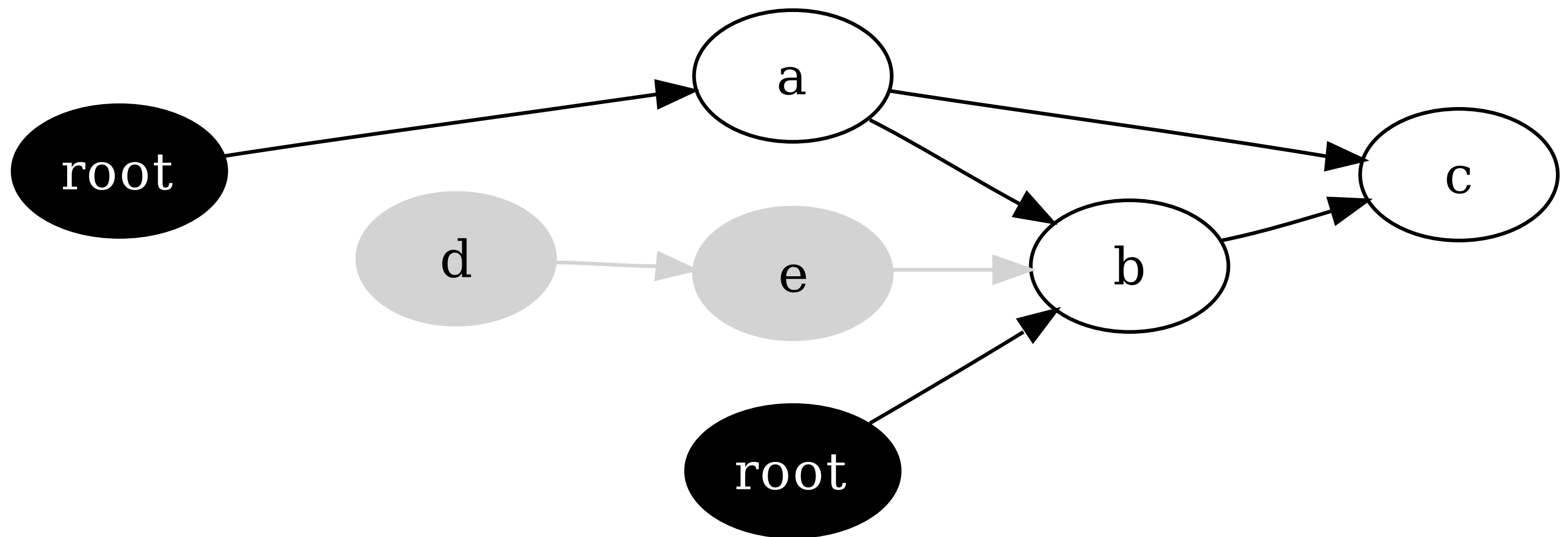
How does garbage collection work?



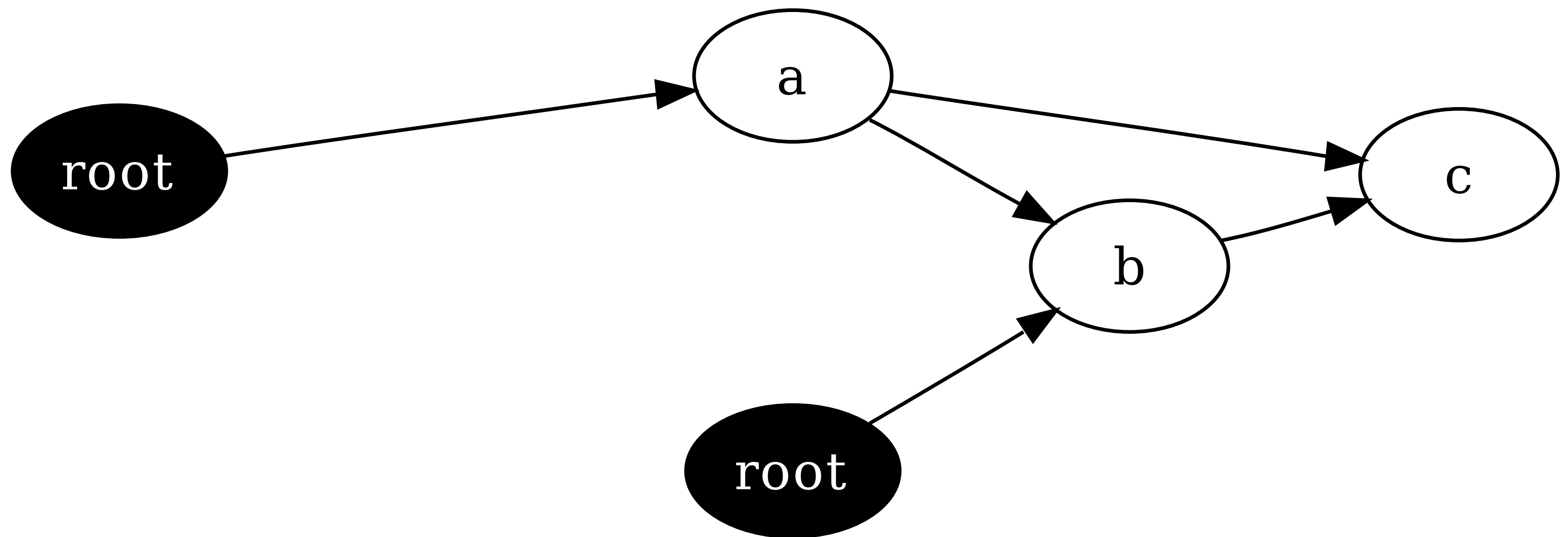
If the reference to D goes away...



We can no longer reach D or E.



So the collector reclaims them.



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)

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()`
 - References (and reference queues)

Try `finally` first.

> Pros:

- More straightforward
- Handles exceptions in main thread
- Ensures cleanup keeps pace

> Cons:

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

> ARM will help.

What is a finalizer?

A callback used by the garbage collector to notify an object when it is about to be reclaimed:

```
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.
- > Undefined threading model; they can run concurrently!
- > You must remember to call `super.finalize()`.
- > Exceptions are ignored (per spec).
- > You can resurrect references.
- > They keep objects alive longer than necessary.
- > They can make allocation/reclamation 430X slower!
(Bloch, *Effective Java*)
- > Worst of all, they messed up the reference API.

Example

```
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 NativeMemory'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());  
    }  
}
```



Always 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);
}
```

Basically, finalizers are good for one thing.

Logging warnings:

```
public class Connection {  
    ...  
    boolean closed;  
    public synchronized void close() {  
        reallyClose();  
        closed = true;  
    }  
    private native void reallyClose();  
  
    @Override protected synchronized void finalize() {  
        if (!closed) {  
            Logger.getLogger(Connection.class.getName())  
                .warning("You forgot to close me!!!");  
            close();  
        }  
    }  
}
```


Basically, finalizers are good for one thing.

Logging warnings:

```
public class Connection {  
    ...  
    boolean closed;  
    public synchronized void close() {  
        reallyClose();  
        closed = true;  
    }  
    private native void reallyClose();  
  
    @Override protected synchronized void finalize() {  
        if (!closed) {  
            Logger.getLogger(Connection.class.getName())  
                .warning("You forgot to close me!!!");  
            close();  
        }  
    }  
}
```

Unless you want to disable the warnings.

The alternative: The Reference API

- > @since 1.2
- > Reference types
 - **Soft:** for caching
 - **Weak:** for fast cleanup (pre-finalizer)
 - **Phantom:** for safe cleanup (post-finalizer)
- > **Reference queues:** for notifications

```
package java.lang.ref
```

```
public abstract class Reference<T> {  
    public T get() { ... }  
}
```

```
public class SoftReference<T> extends Reference<T> {  
    public SoftReference(T referent) { ... }  
    public SoftReference(T referent, ReferenceQueue<? super T> q) { ... }  
}
```

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

```
public class PhantomReference<T> extends Reference<T> {  
    public PhantomReference(T referent, ReferenceQueue<? super T> q) { ... }  
}
```

```
public class ReferenceQueue<T> {  
    public ReferenceQueue() { ... }  
    public Reference<? extends T> poll() { ... }  
    public Reference<? extends T> remove() { ... }  
}
```

Soft references

- > Cleared when the VM runs low on memory
 - *Hopefully* in LRU fashion
- > Tuned with `-XX:SoftRefLRUPolicyMSPerMB`
 - How long to retain soft refs in *ms per free MB of heap*
 - **Default:** 1000ms

Use soft references judiciously.

- > For quick-and-dirty caching only
- > Soft refs have no notion of *weight*:
 - Memory usage
 - Computation time
 - CPU usage
- > Soft refs can exacerbate low memory conditions.

Caching a file

```
public class CachedFile {
    final File file;
    public CachedFile(File file) {
        this.file = file;
    }
    volatile SoftReference<byte[]> dataReference
        = new SoftReference<byte[]>(null);
    /** Gets file contents, reading them if necessary. */
    public byte[] getData() {
        byte[] data = dataReference.get();
        if (data != null) return data;
        data = readData();
        dataReference = new SoftReference<byte[]>(data);
        return data;
    }
    /** Reads file contents. */
    byte[] readData() {
        ...
    }
}
```

Weak references

- > Cleared as soon as no strong or soft refs remain.
- > Cleared ASAP, before the finalizer runs.
- > **Not for caching!** Use soft references, as intended:

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

- The `SoftReference` documentation

Can you hear me now?

```
public class Button {
    public interface Listener {
        void onClick();
    }
    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();
        }
    }
}
```

Phantom references

- > Enqueued after no other references remain, *post-finalizer*.
 - Can suffer similar problems to finalizers.
- > Must be cleared manually, for no good reason.
- > `get ()` always returns `null`.
 - So you must use a reference queue.

Accessing a phantom referent

```
public class WeakPhantomReference<T> extends PhantomReference<T> {
    final WeakReference<T> weakReference;

    public WeakPhantomReference(T referent,
        ReferenceQueue<? super T> q) {
        super(referent, q);
        weakReference = new WeakReference<T>(referent);
    }

    /** Returns referent so long as it's weakly-reachable. */
    @Override public T get() {
        return weakReference.get();
    }
}
```

Let's replace a finalizer!

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

    /** 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);
}
```

The reference

```
class NativeMemoryReference
    extends PhantomReference<NativeMemory> {
    final int address;
    NativeMemoryReference(NativeMemory referent,
        ReferenceQueue<NativeMemory> rq) {
        super(referent, rq);
        address = referent.address;
    }
}
```

The manager

```
public class NativeMemoryManager {
    private static final Set<Reference<?>> refs
        = Collections.synchronizedSet(new HashSet<Reference<?>>());
    private static final ReferenceQueue<NativeMemory> rq
        = new ReferenceQueue<NativeMemory>();
    public static NativeMemory allocate() {
        NativeMemory nm = new NativeMemory();
        refs.add(new NativeMemoryReference(nm, rq));
        cleanUp();
        return nm;
    }
    private static void cleanUp() {
        NativeMemoryReference ref;
        while ((ref = (NativeMemoryReference) rq.poll()) != null) {
            NativeMemory.free(ref.address);
            refs.remove(ref);
        }
    }
}
```

The manager *with Google Collections*

```
public class NativeMemoryManager {
    private static final Set<Reference<?>> refs
        = Collections.synchronizedSet(new HashSet<Reference<?>>());
    private static final FinalizableReferenceQueue frq
        = new FinalizableReferenceQueue();
    public static NativeMemory allocate() {
        NativeMemory nm = new NativeMemory();
        final int address = nm.address;
        refs.add(new FinalizablePhantomReference<NativeMemory>(nm, frq) {
            public void finalizeReferent() {
                NativeMemory.free(address);
                refs.remove(this);
            }
        });
        return nm;
    }
}
```


MapMaker

```
public class GetterMethods {  
    final static Map<Class<?>, List<Method>> cache = new MapMaker()  
        .weakKeys()  
        .softValues()  
        .makeComputingMap(new Function<Class<?>, List<Method>>() {  
            public List<Method> apply(Class<?> clazz) {  
                List<Method> getters = new ArrayList<Method>();  
                for (Method m : clazz.getMethods())  
                    if (m.getName().startsWith("get"))  
                        getters.add(m);  
                return getters;  
            }  
        })  
;  
    public static List<Method> on(Class<?> clazz) {  
        return cache.get(clazz);  
    }  
}
```

Usage: `List<Method> l = GetterMethods.on(Foo.class);`

Recap: The Levels of Reachability

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

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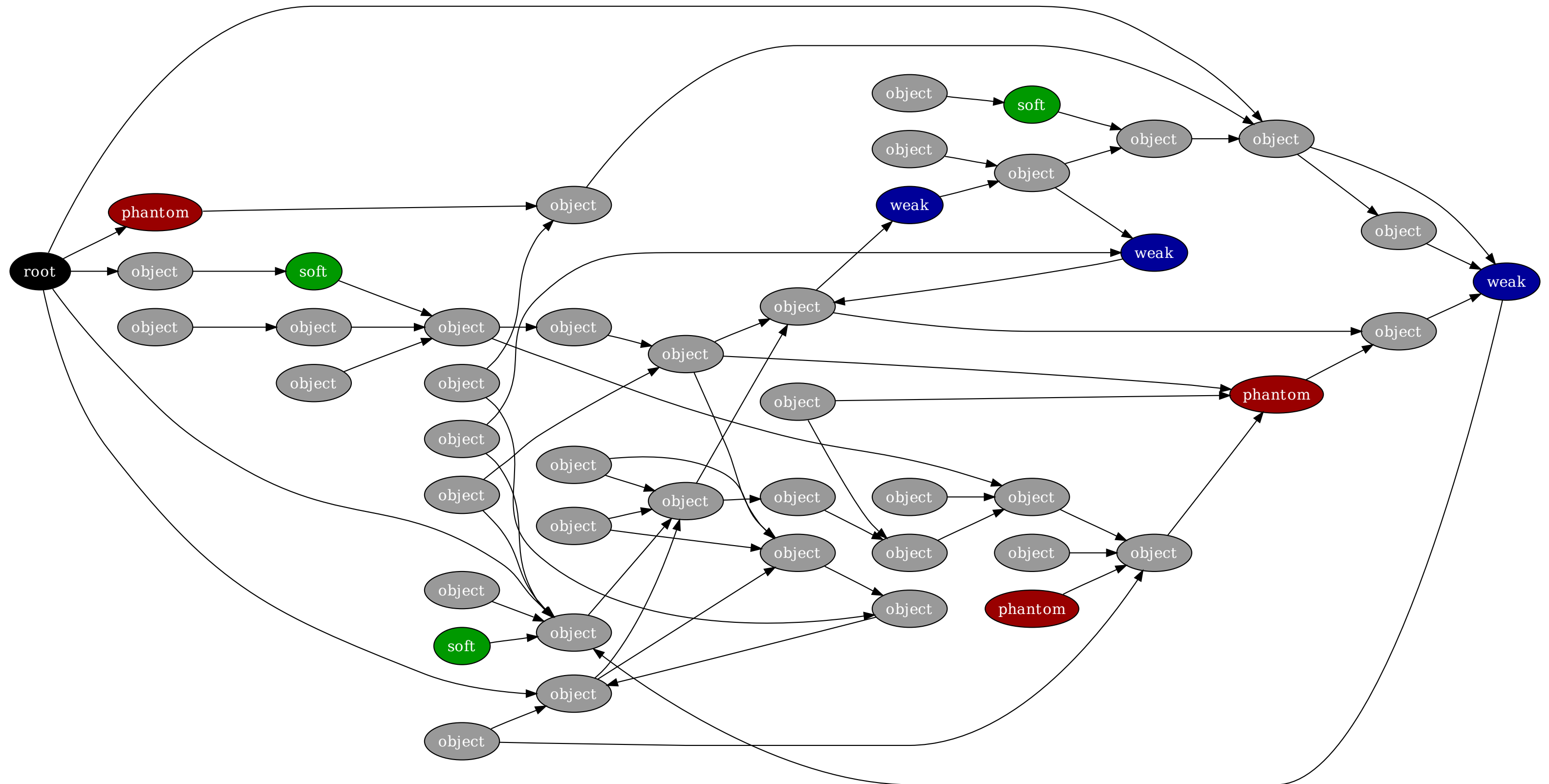
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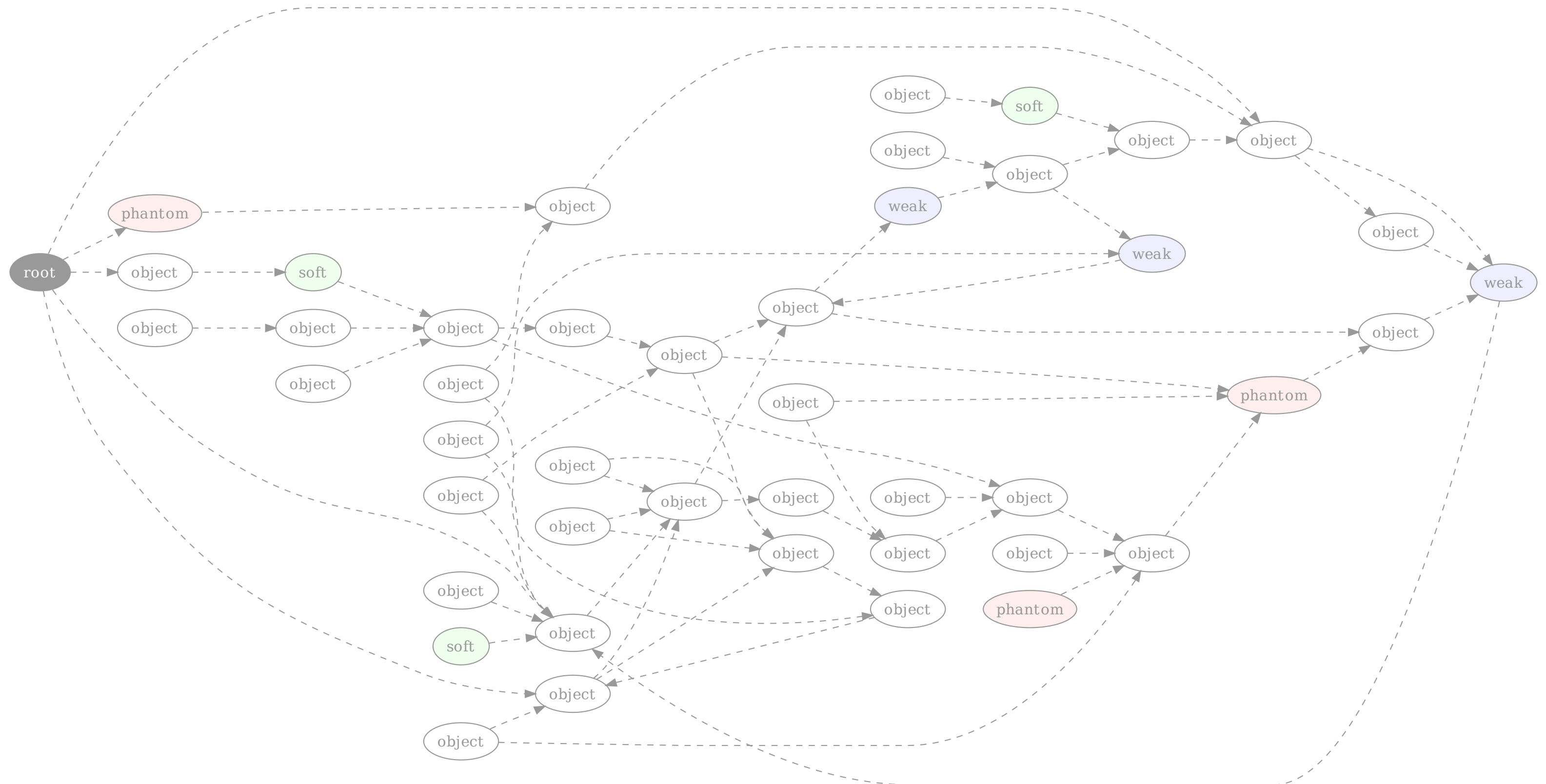
Recap: The Levels of Reachability

- > Strong
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- > Finalizer
- > Phantom, JNI weak
- > **Unreachable**

Let's mark and sweep a heap!



No objects are marked at first.



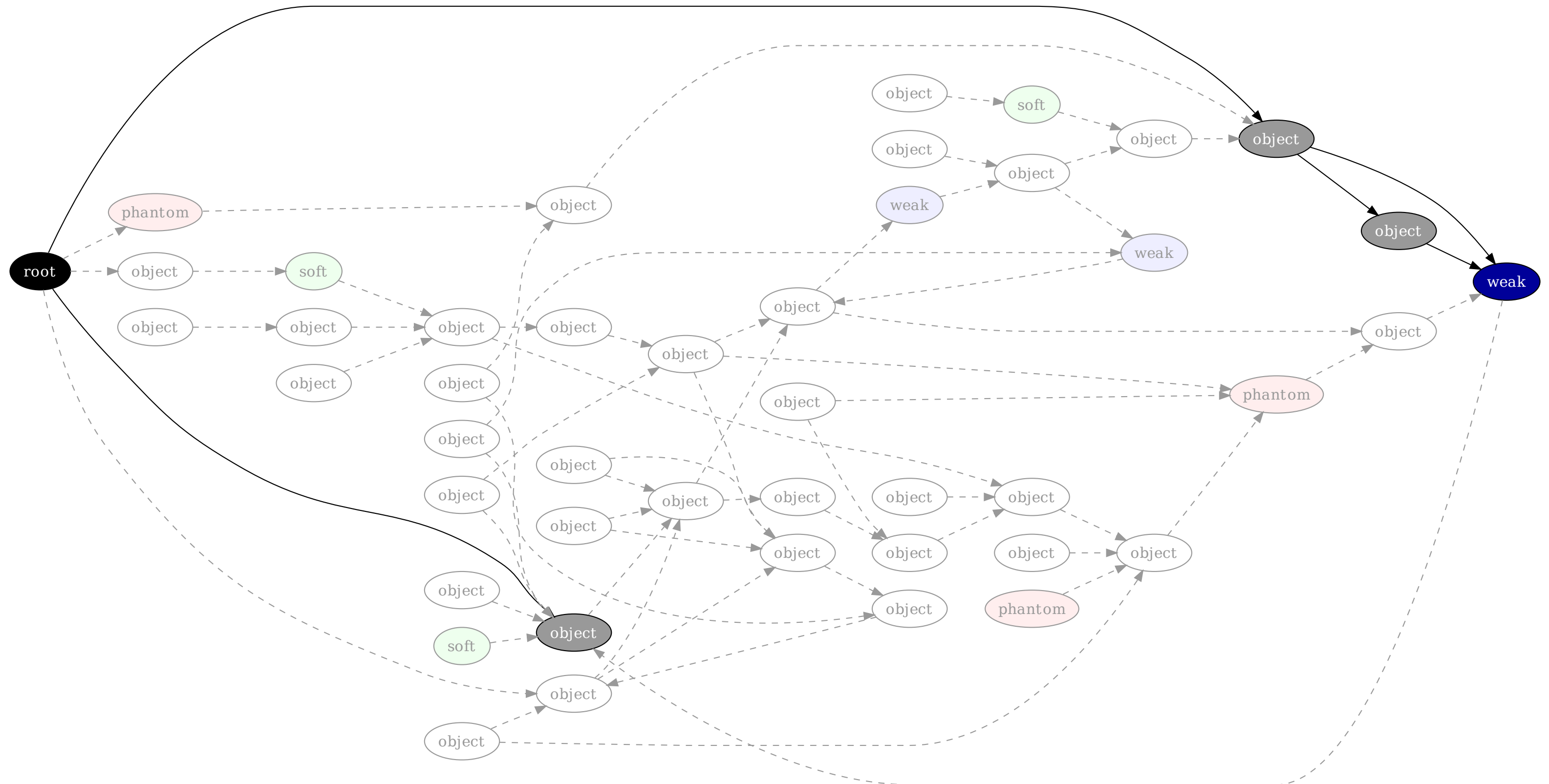
1. Start at a root.



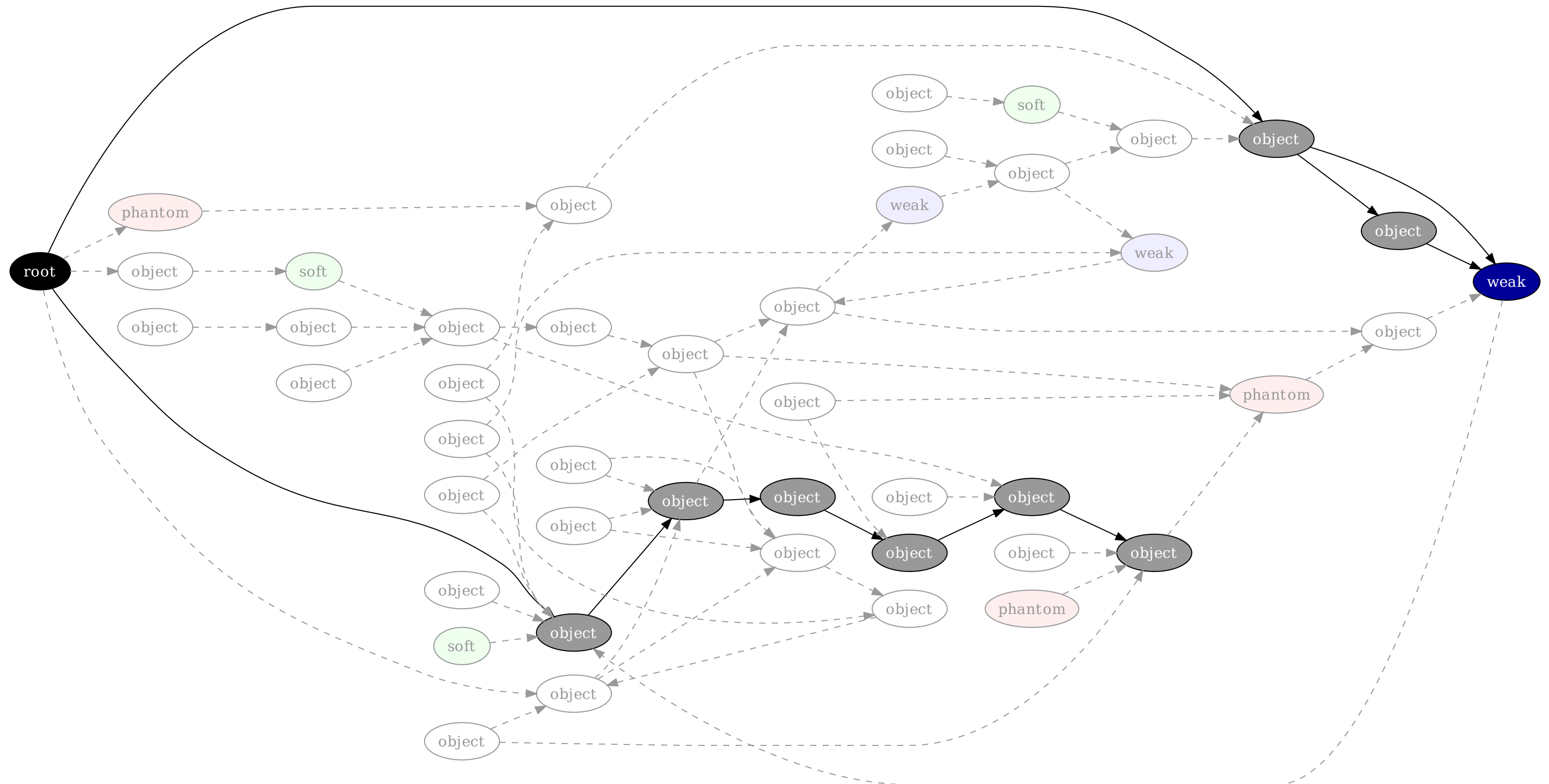
2. Trace and mark strongly-referenced objects.



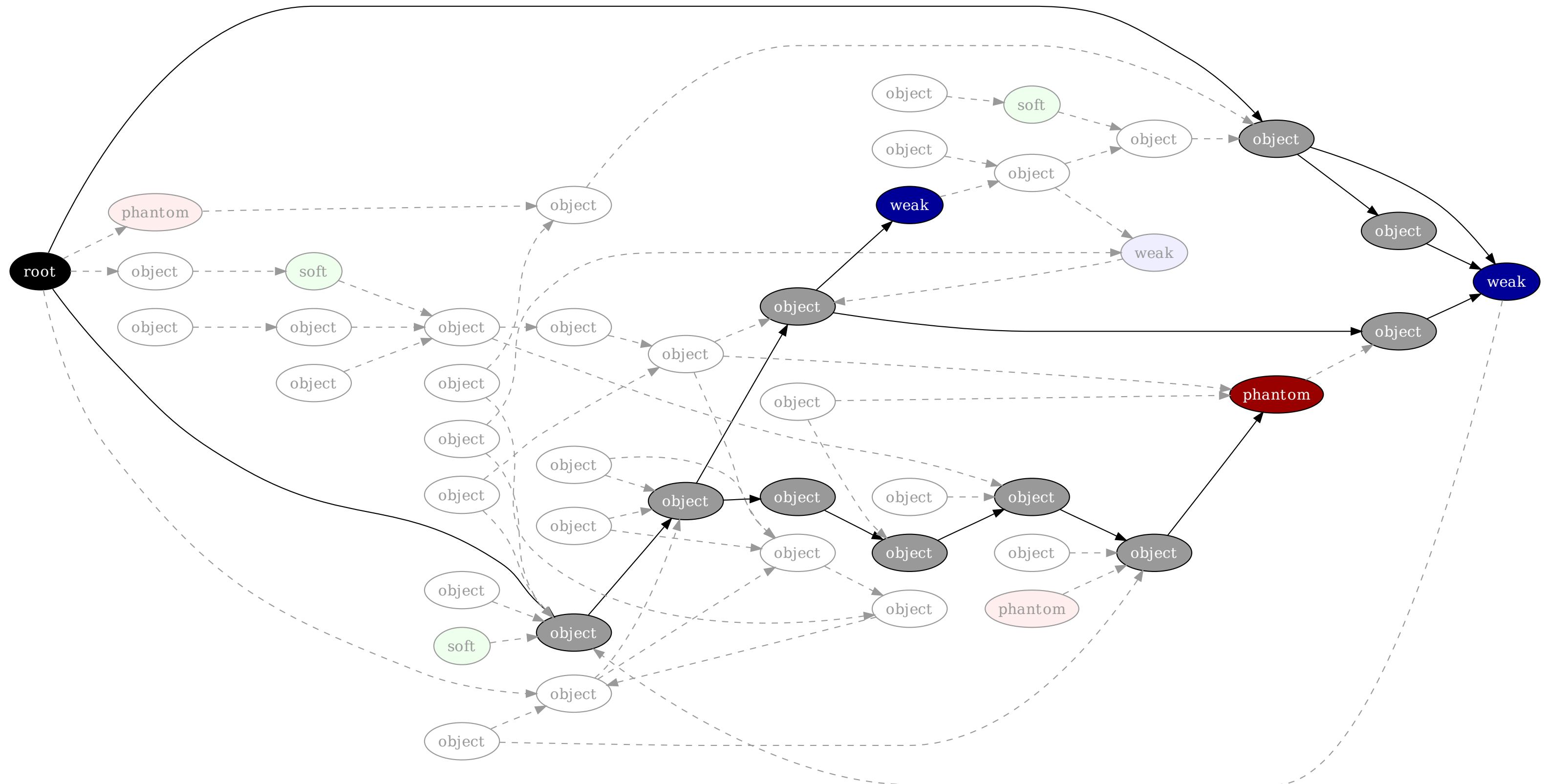
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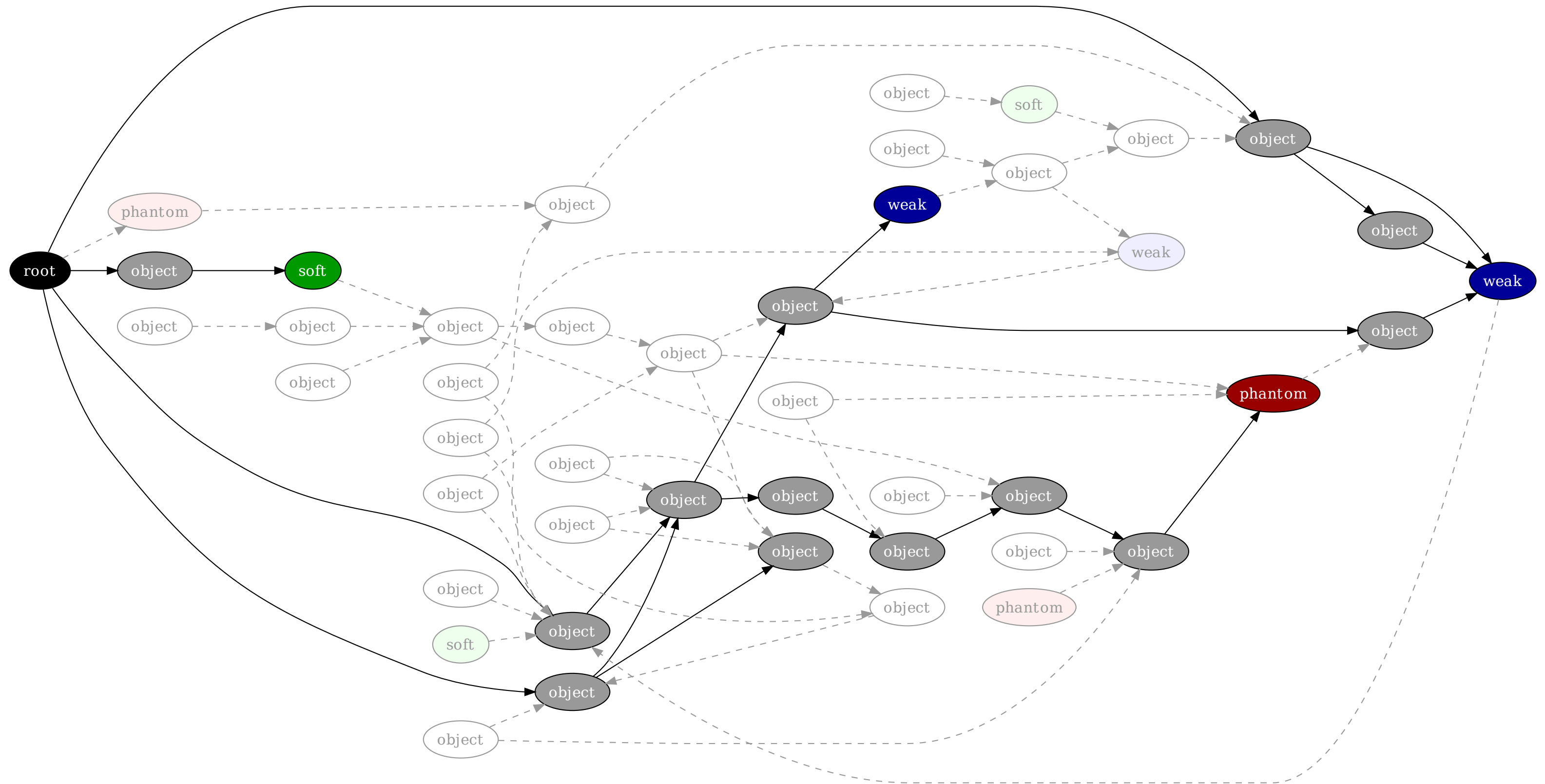
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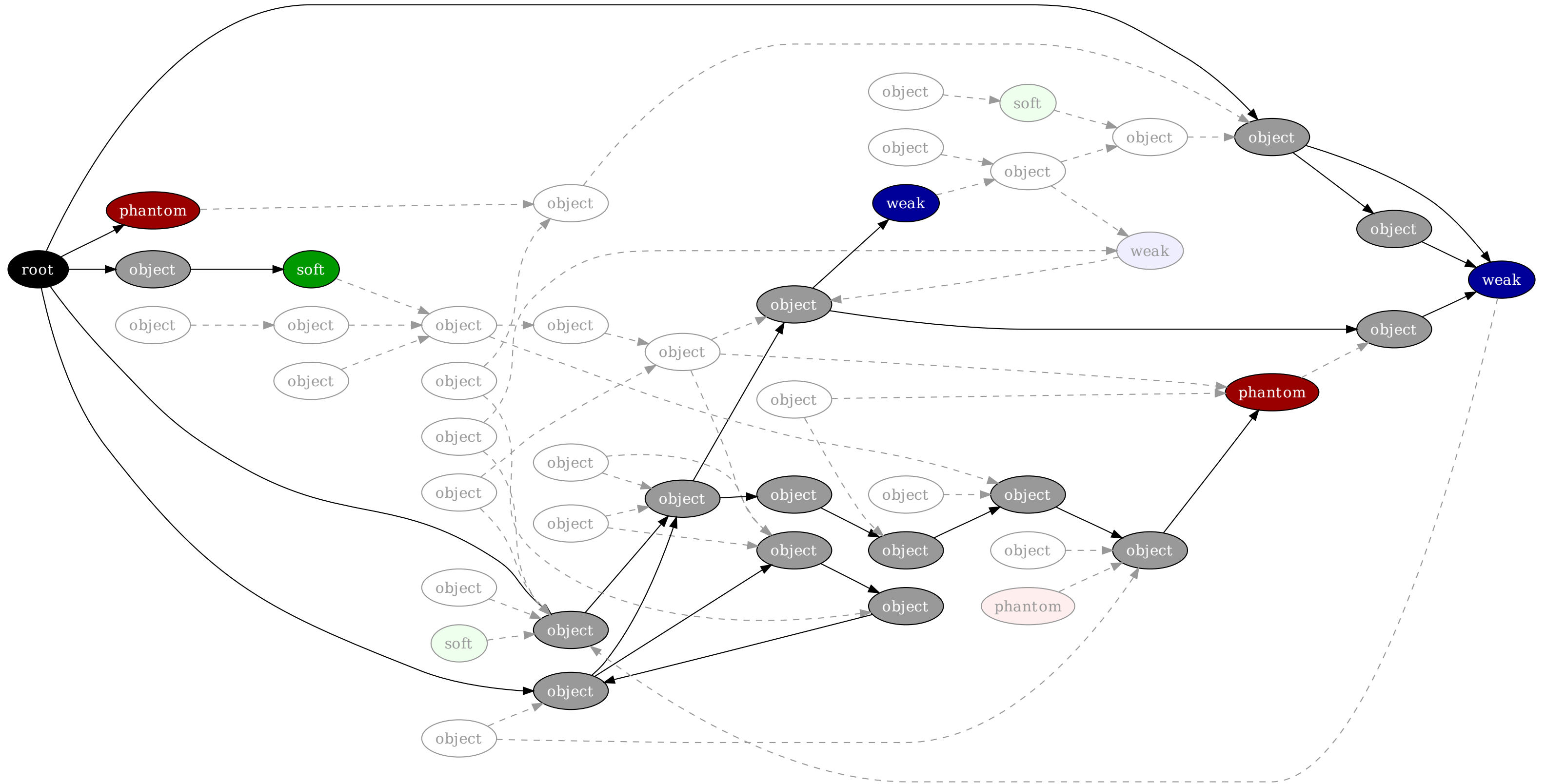
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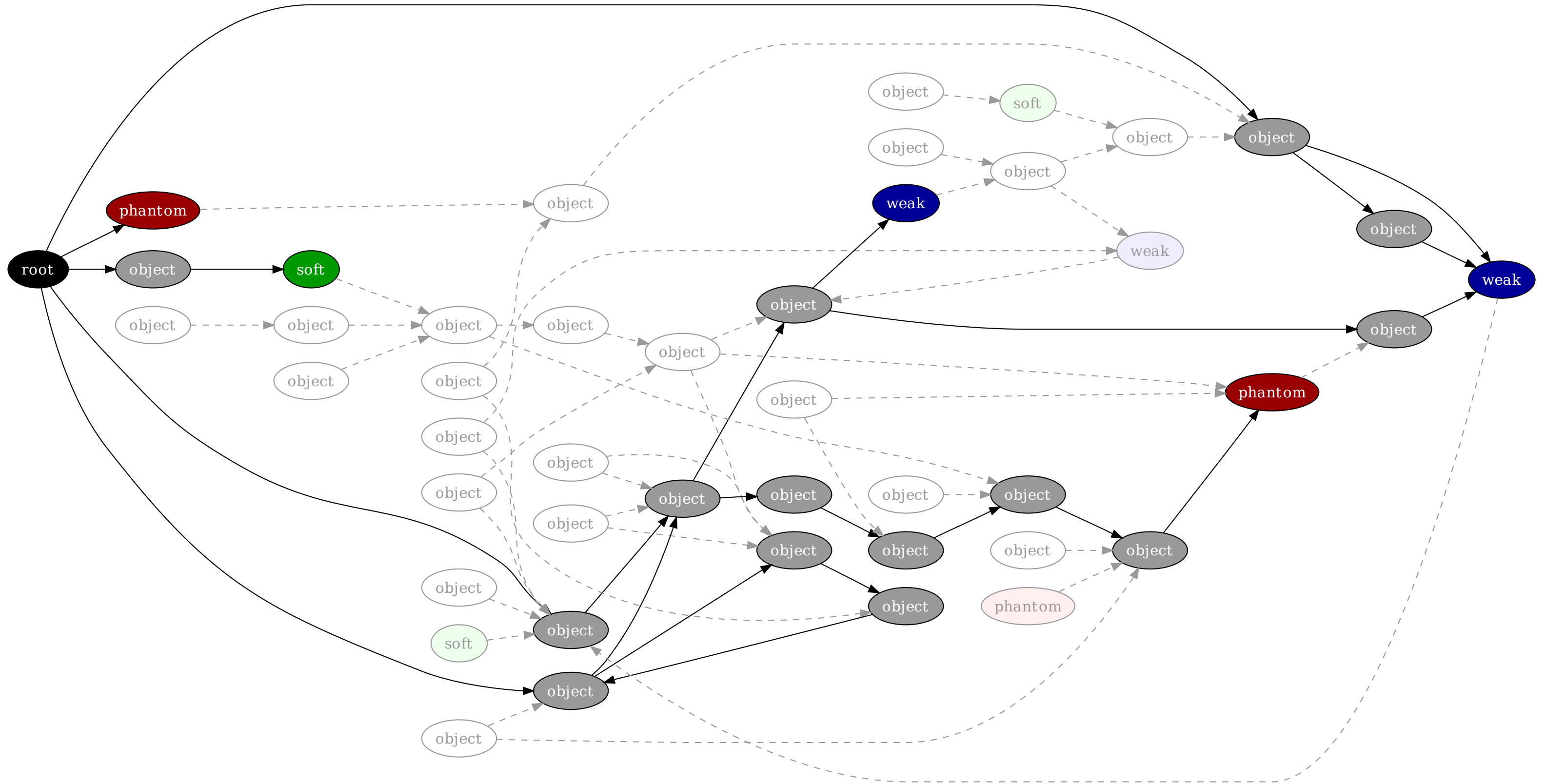
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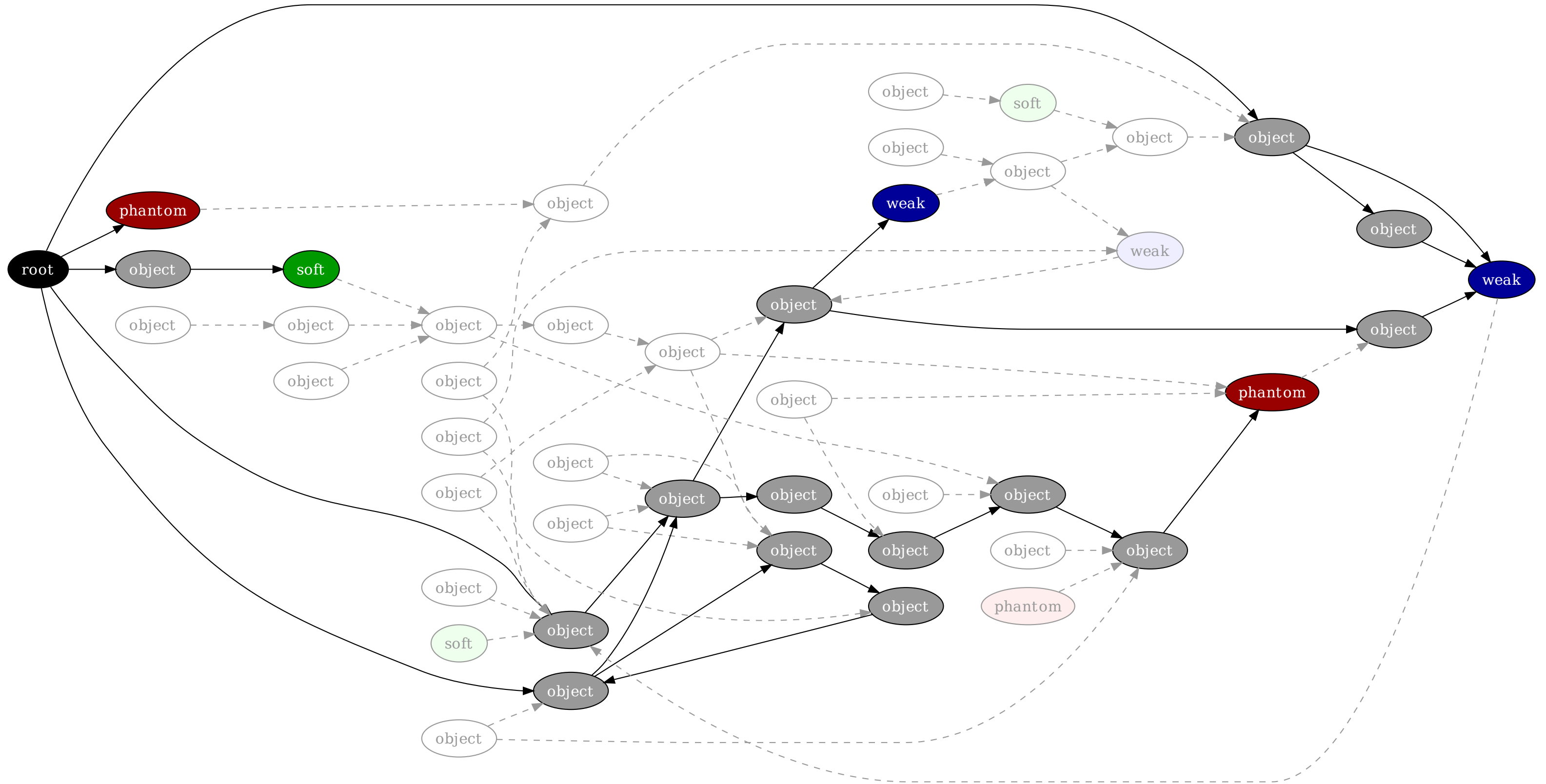
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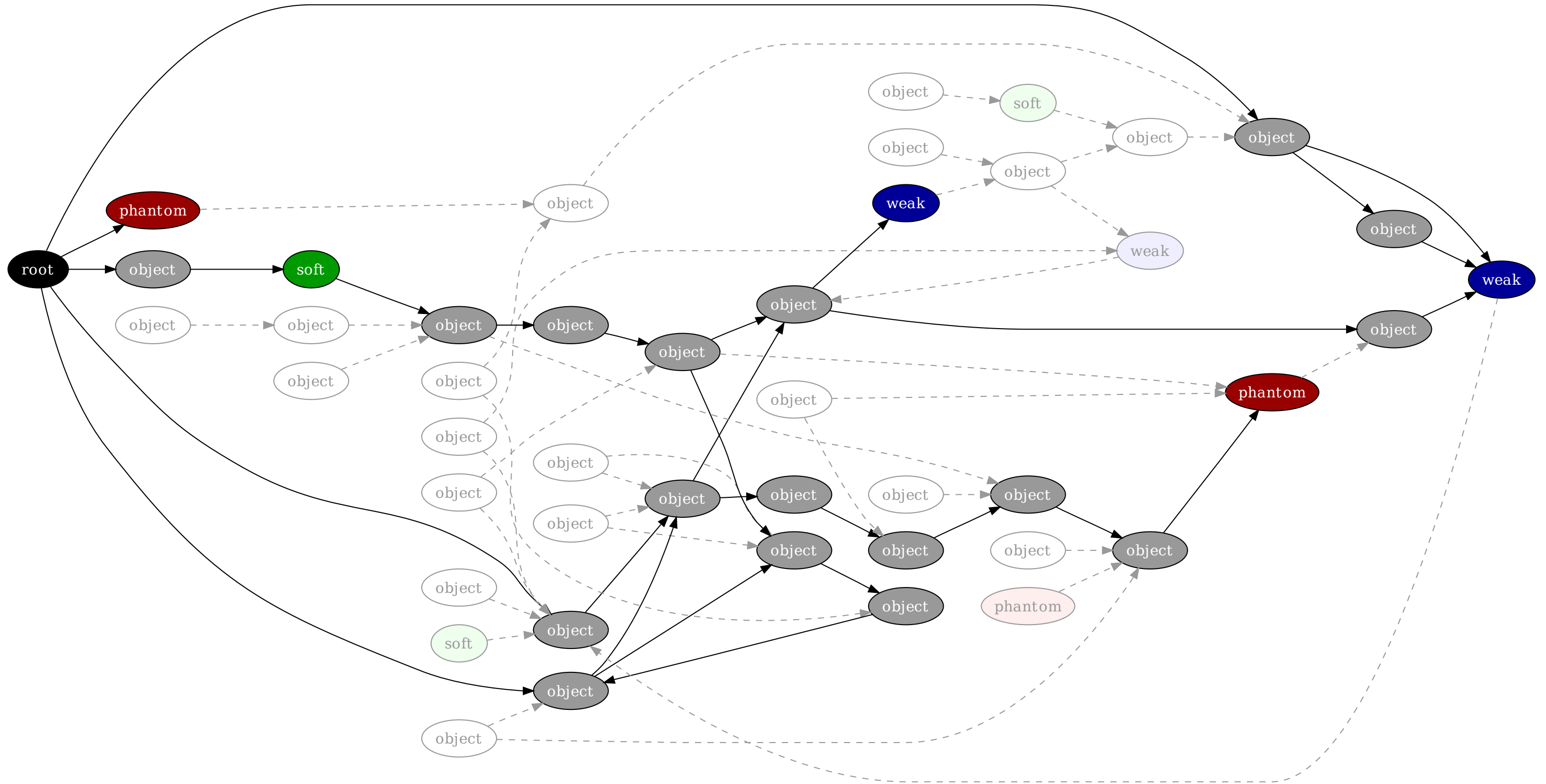
3. Optionally clear soft references.



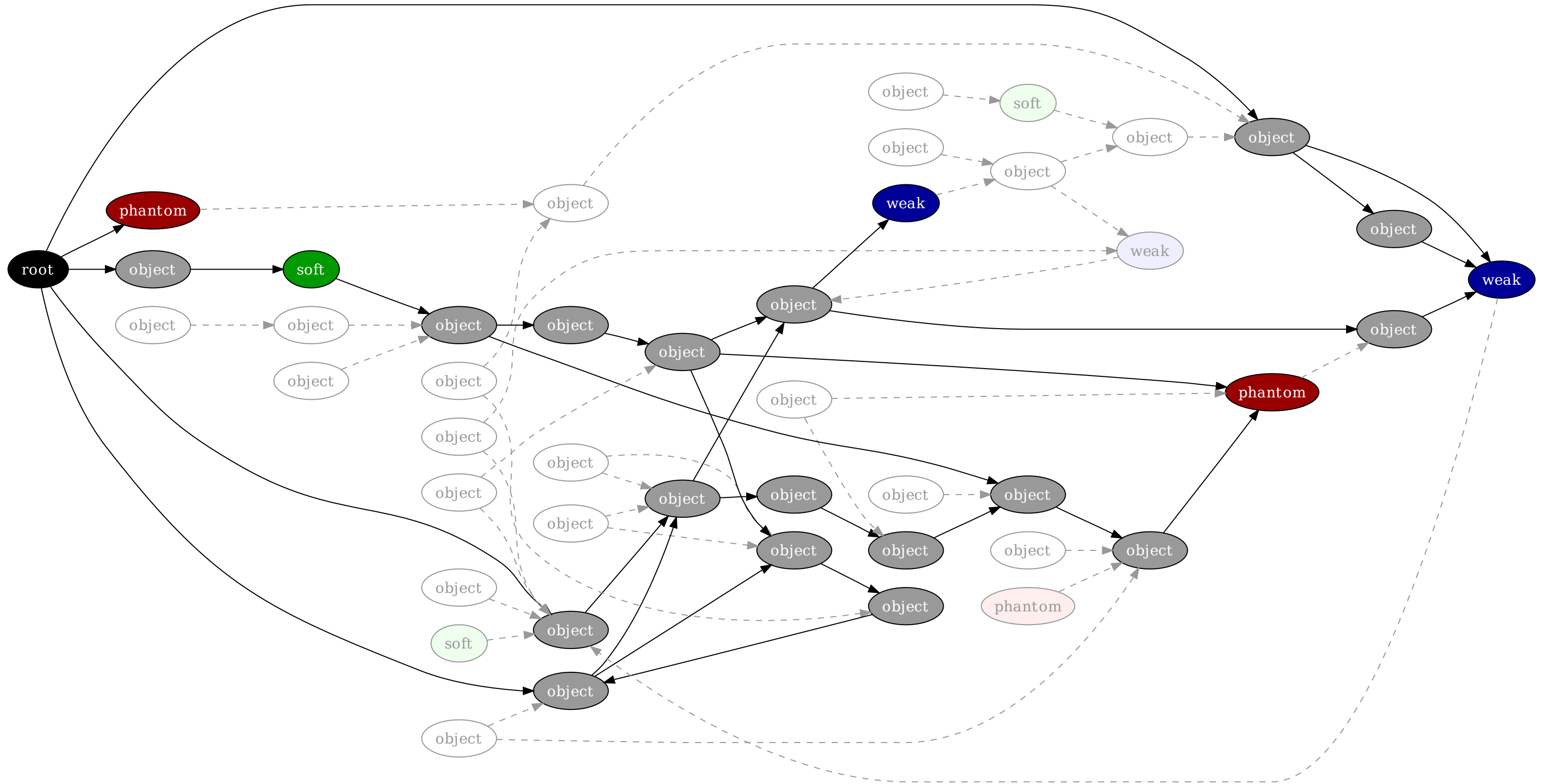
4. Trace and mark softly-referenced objects.



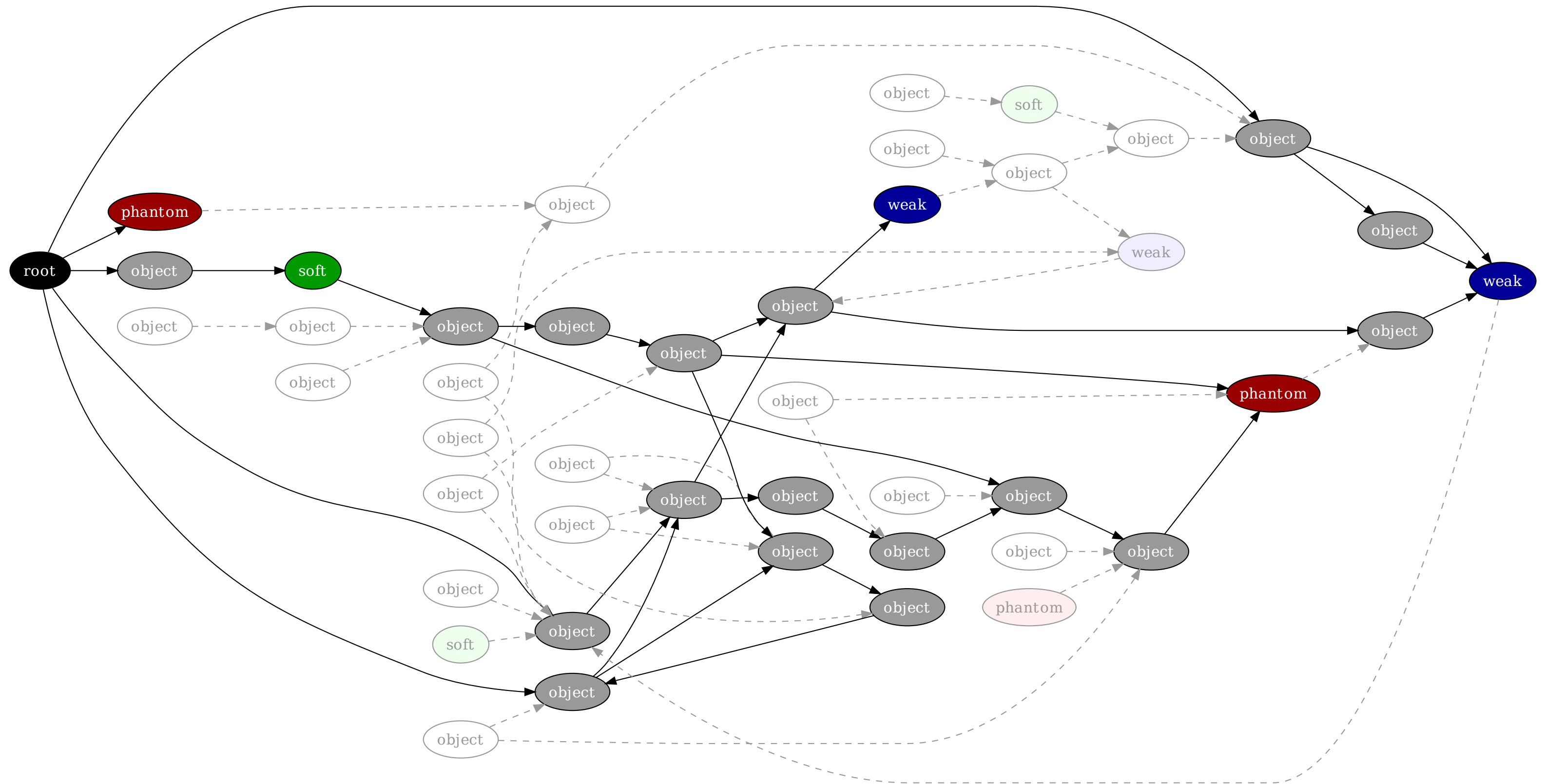
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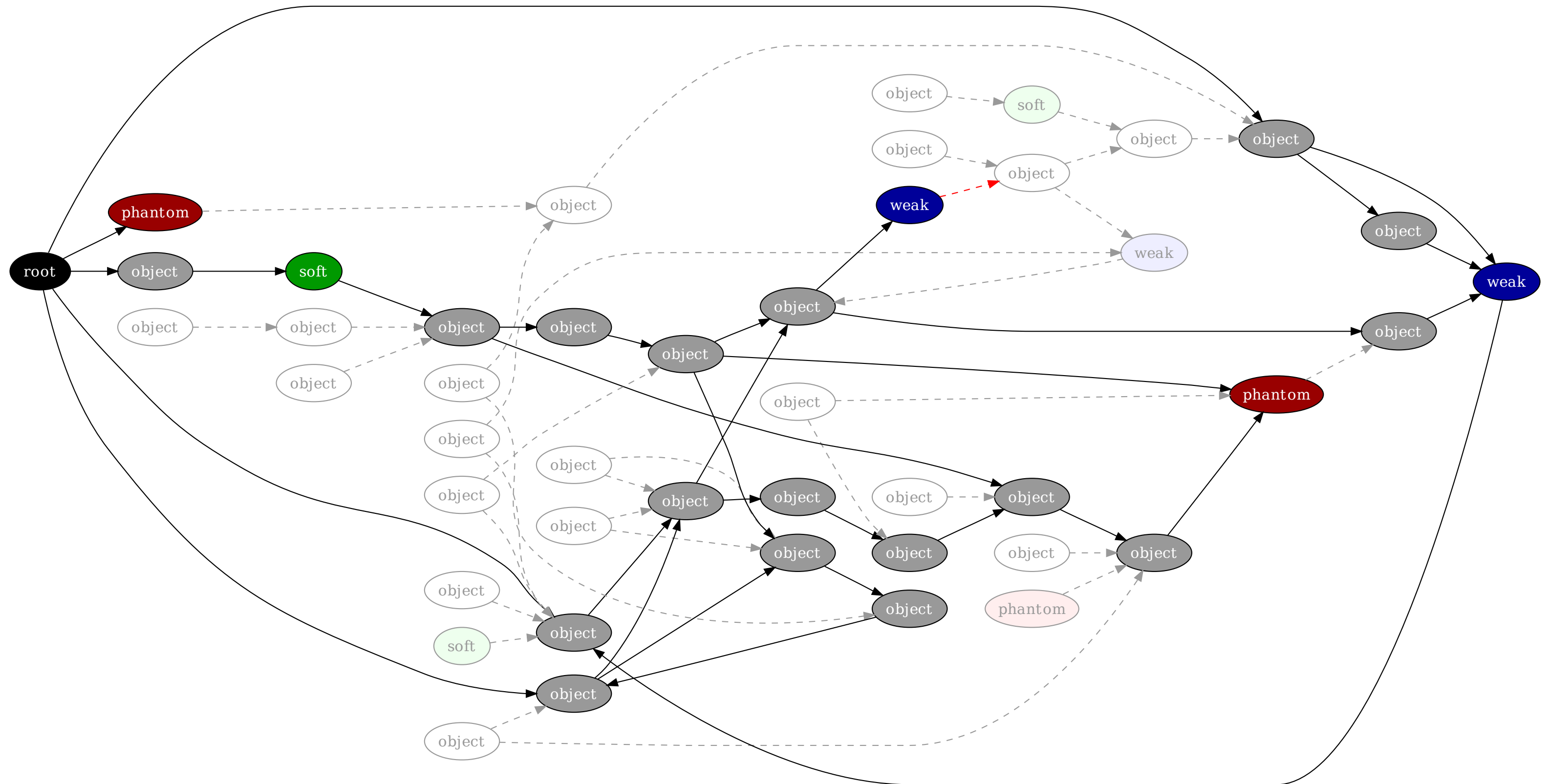
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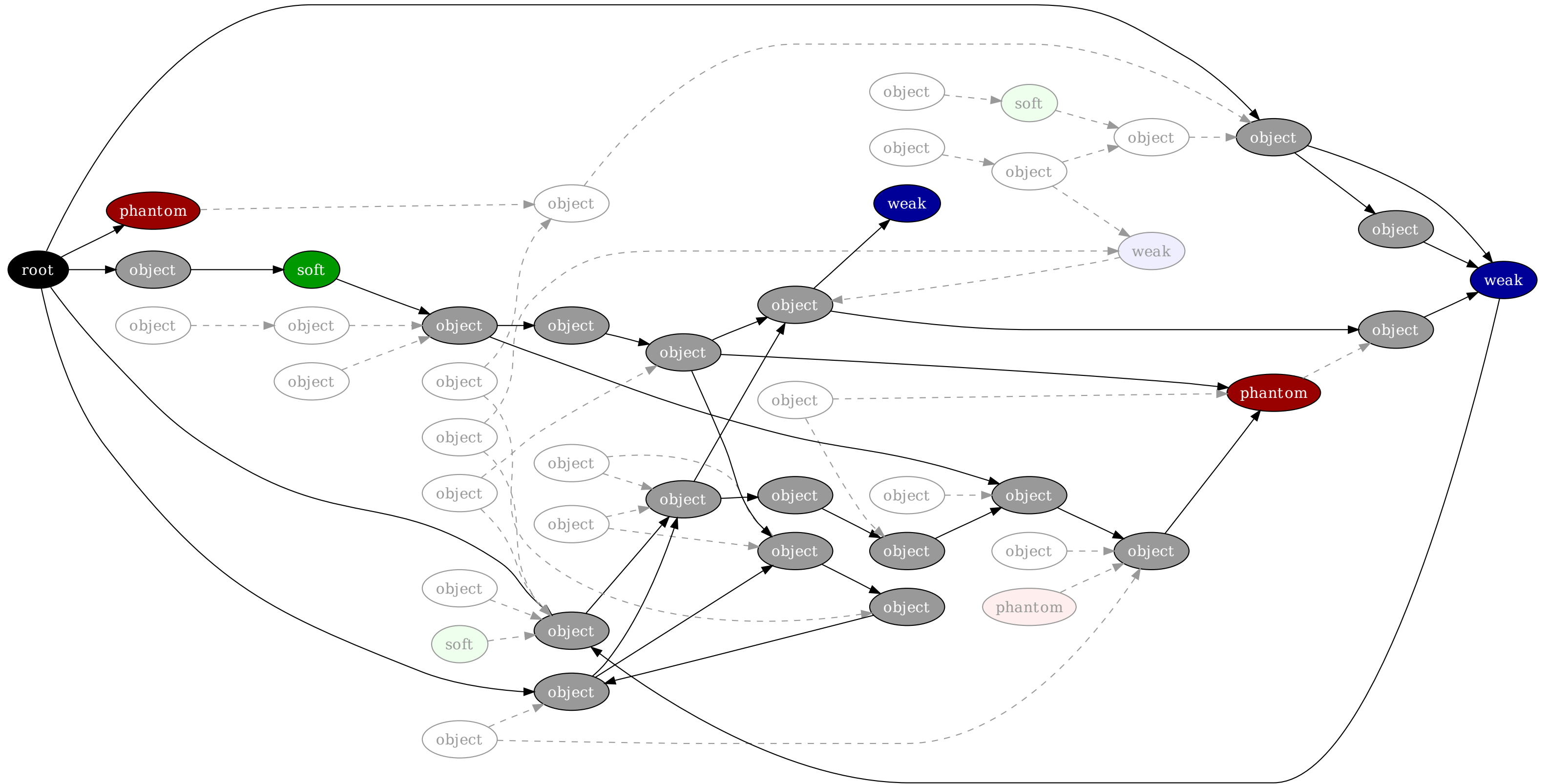
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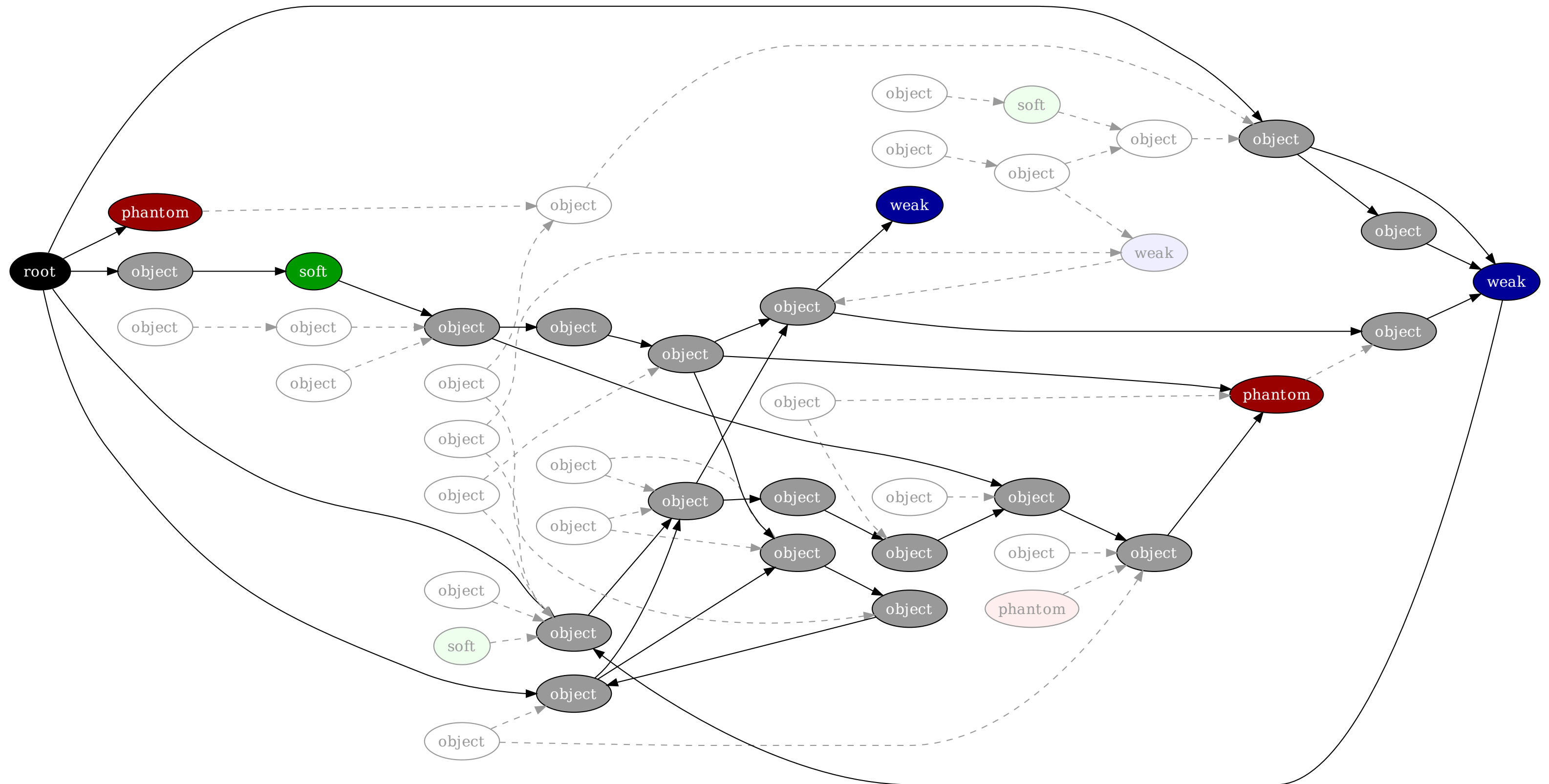
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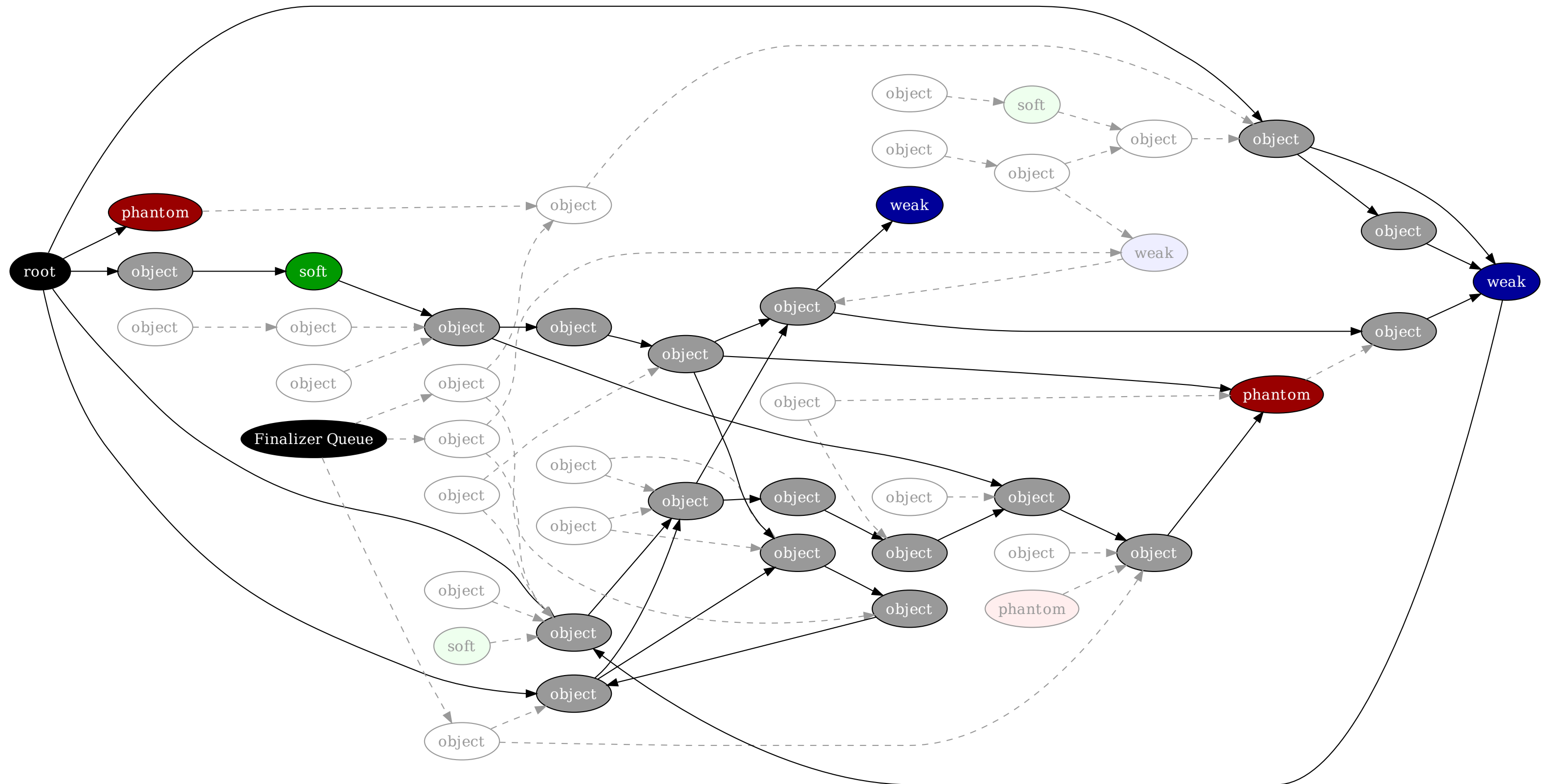
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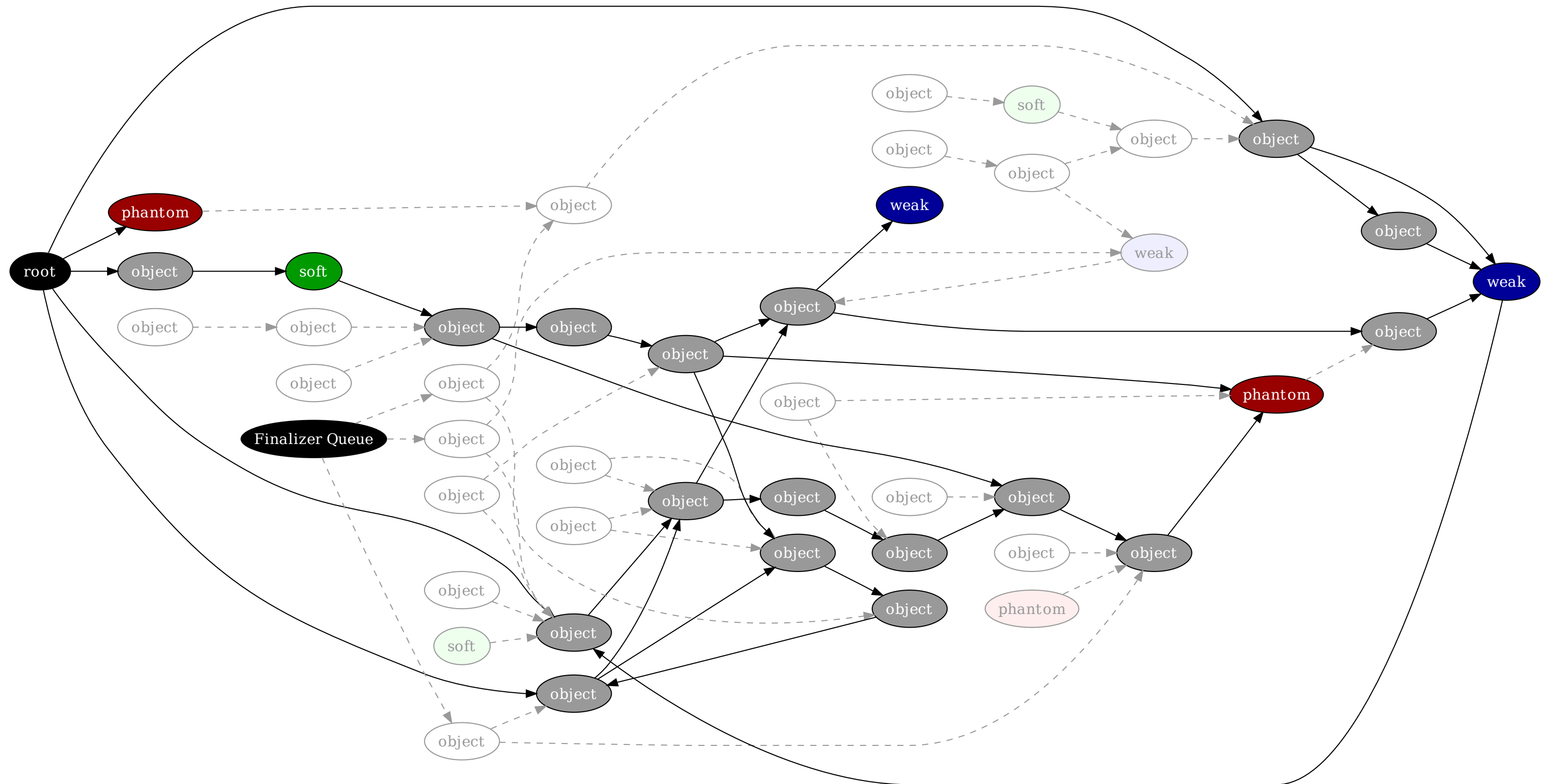
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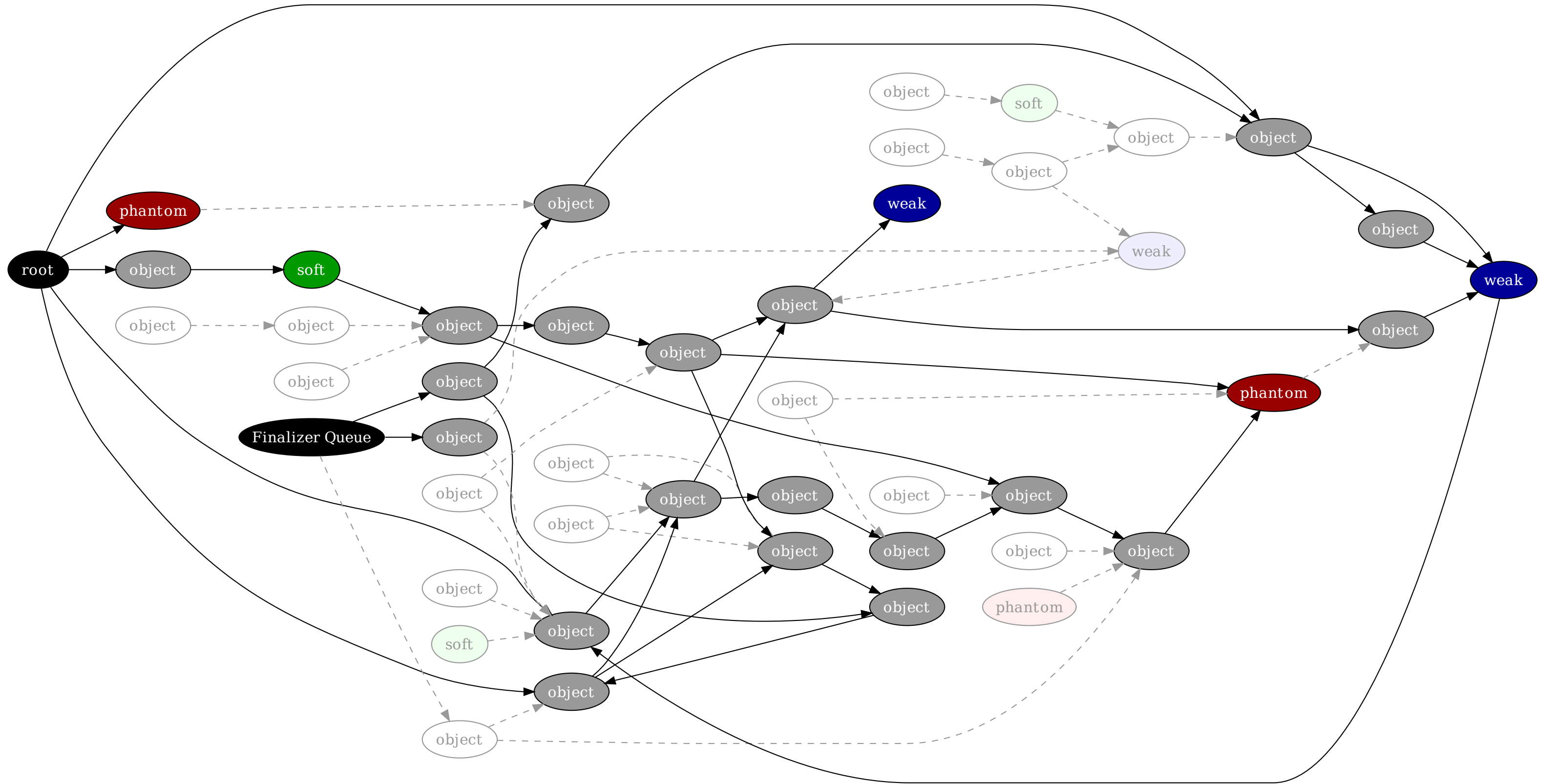
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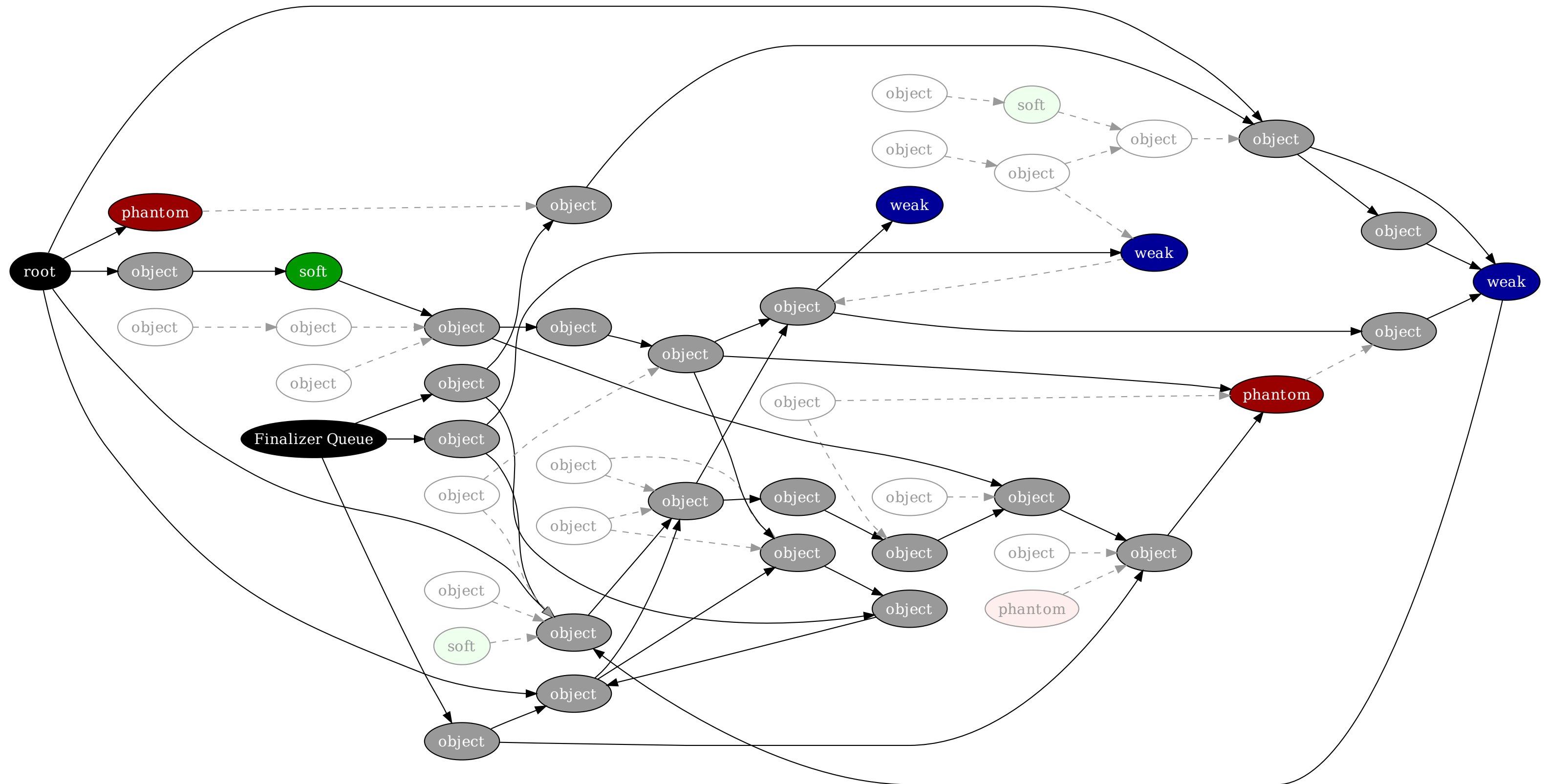
7. Repeat steps 1 through 5 for the queue.



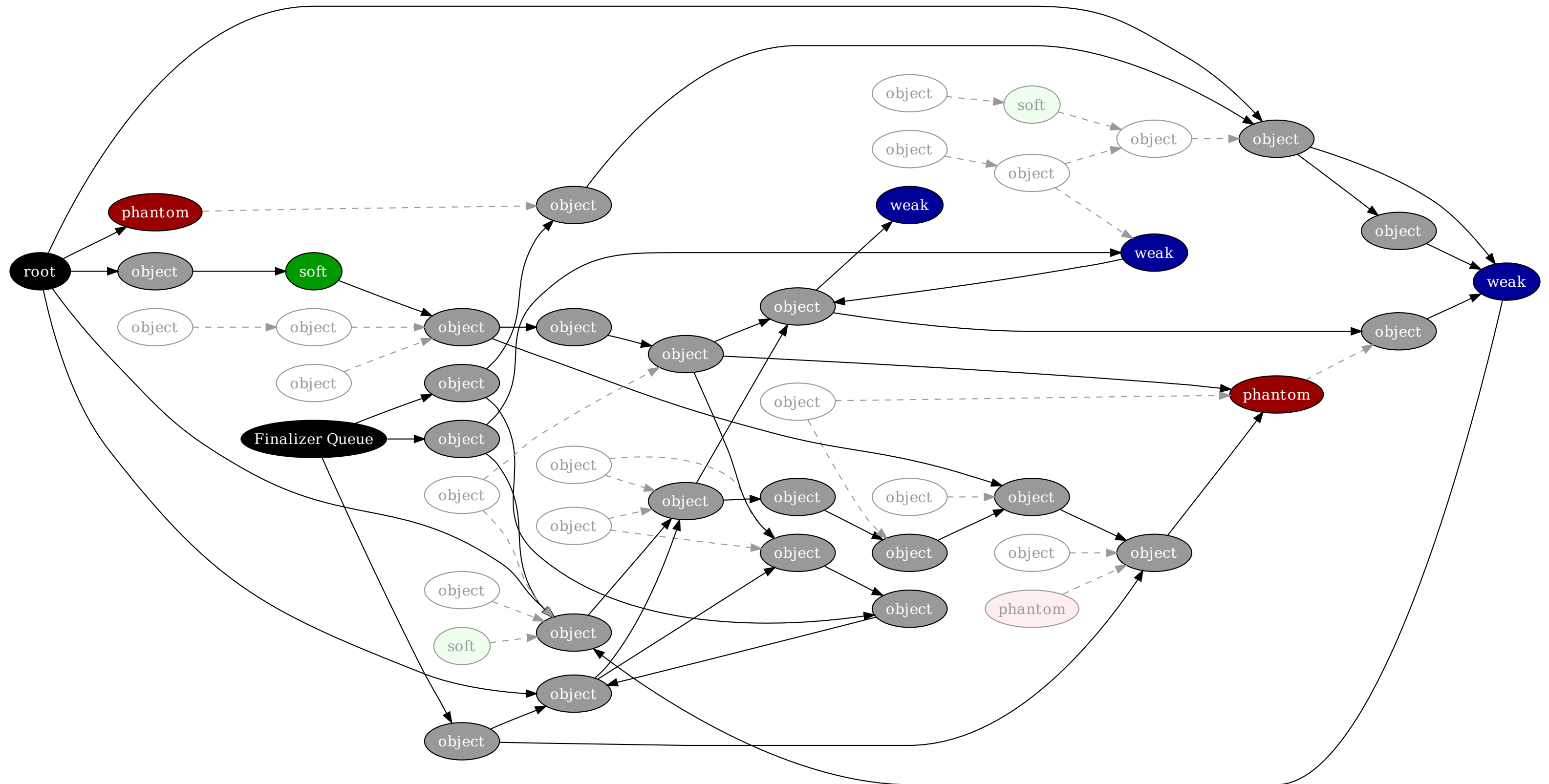
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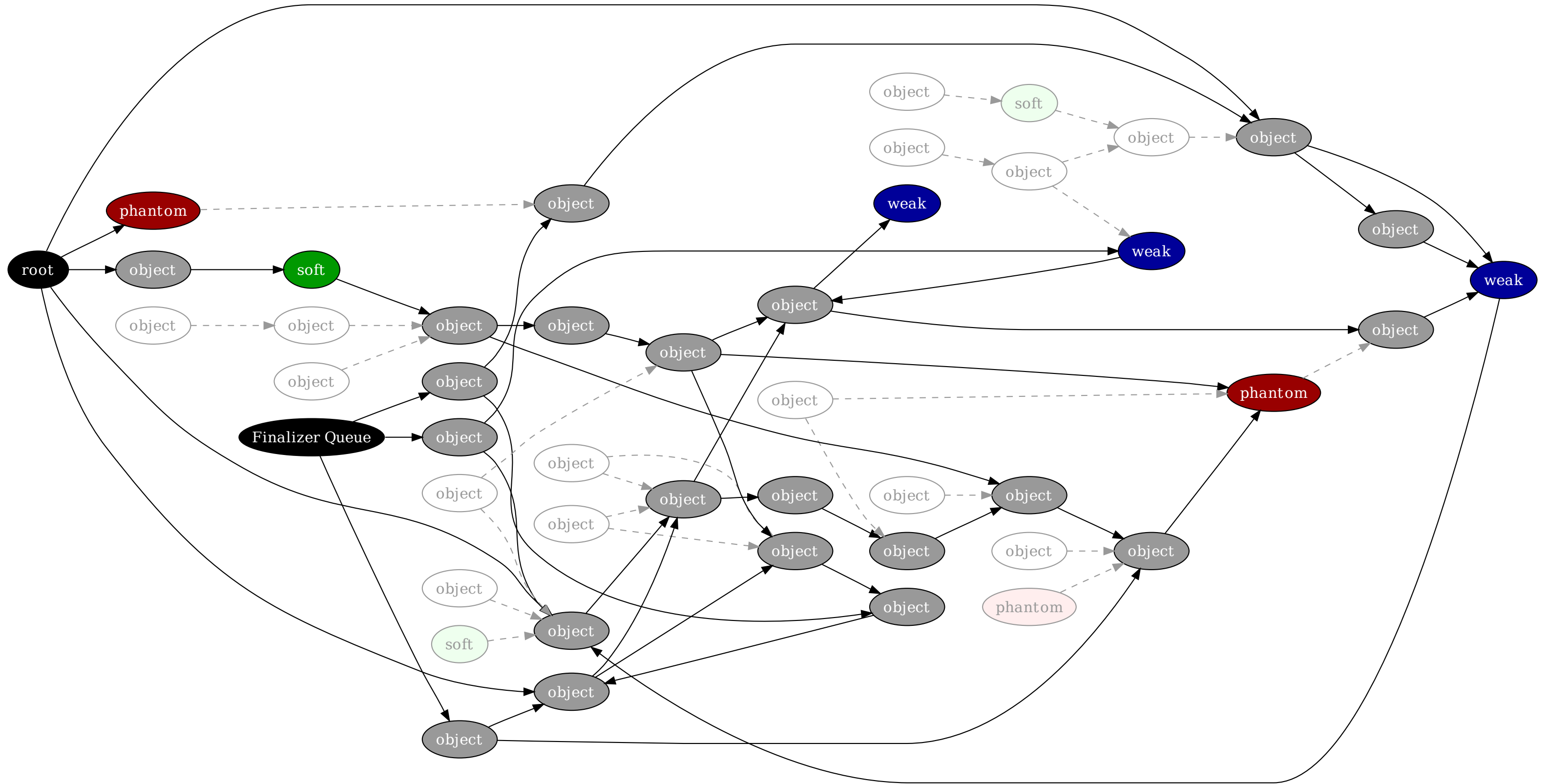
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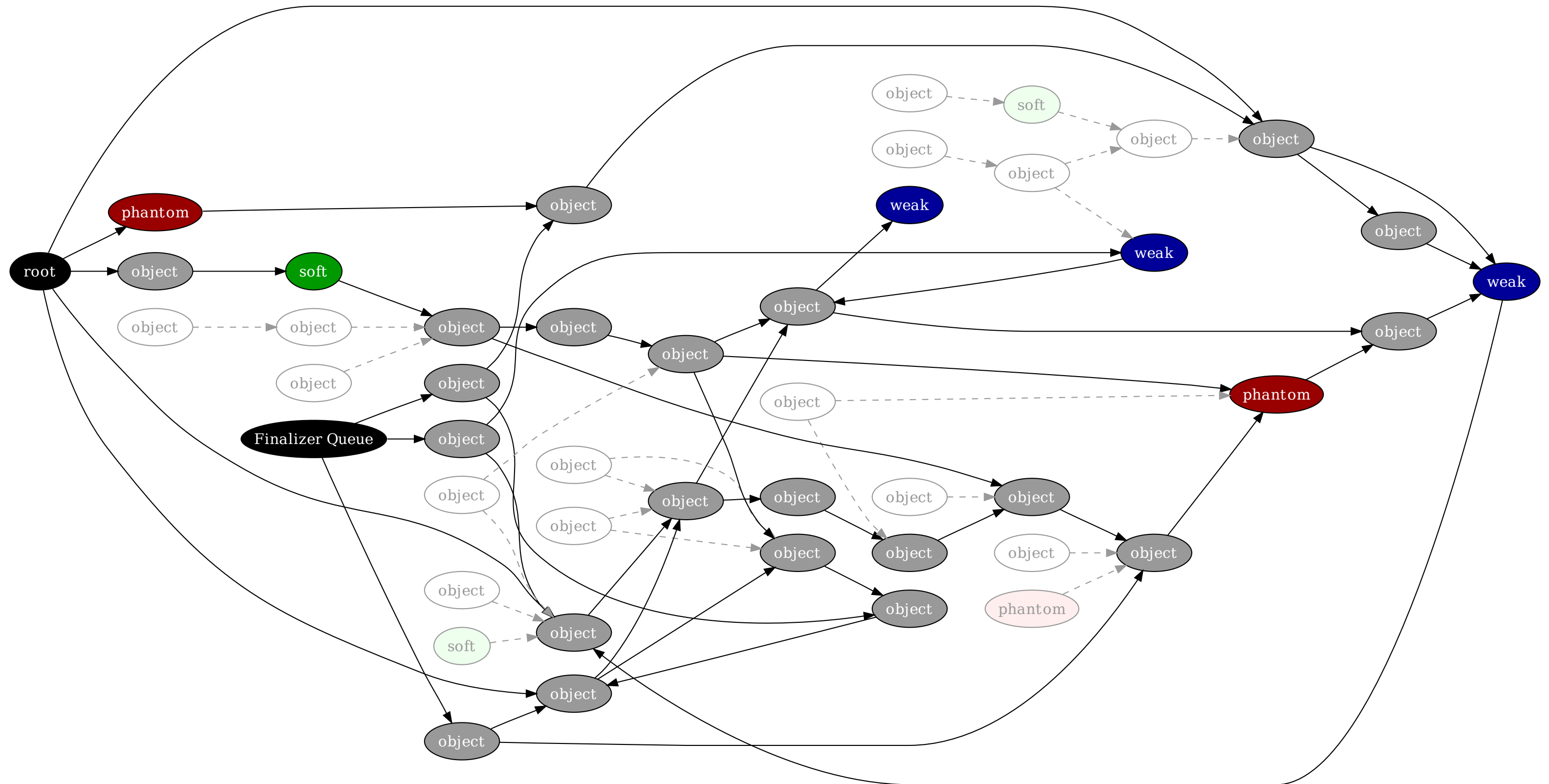
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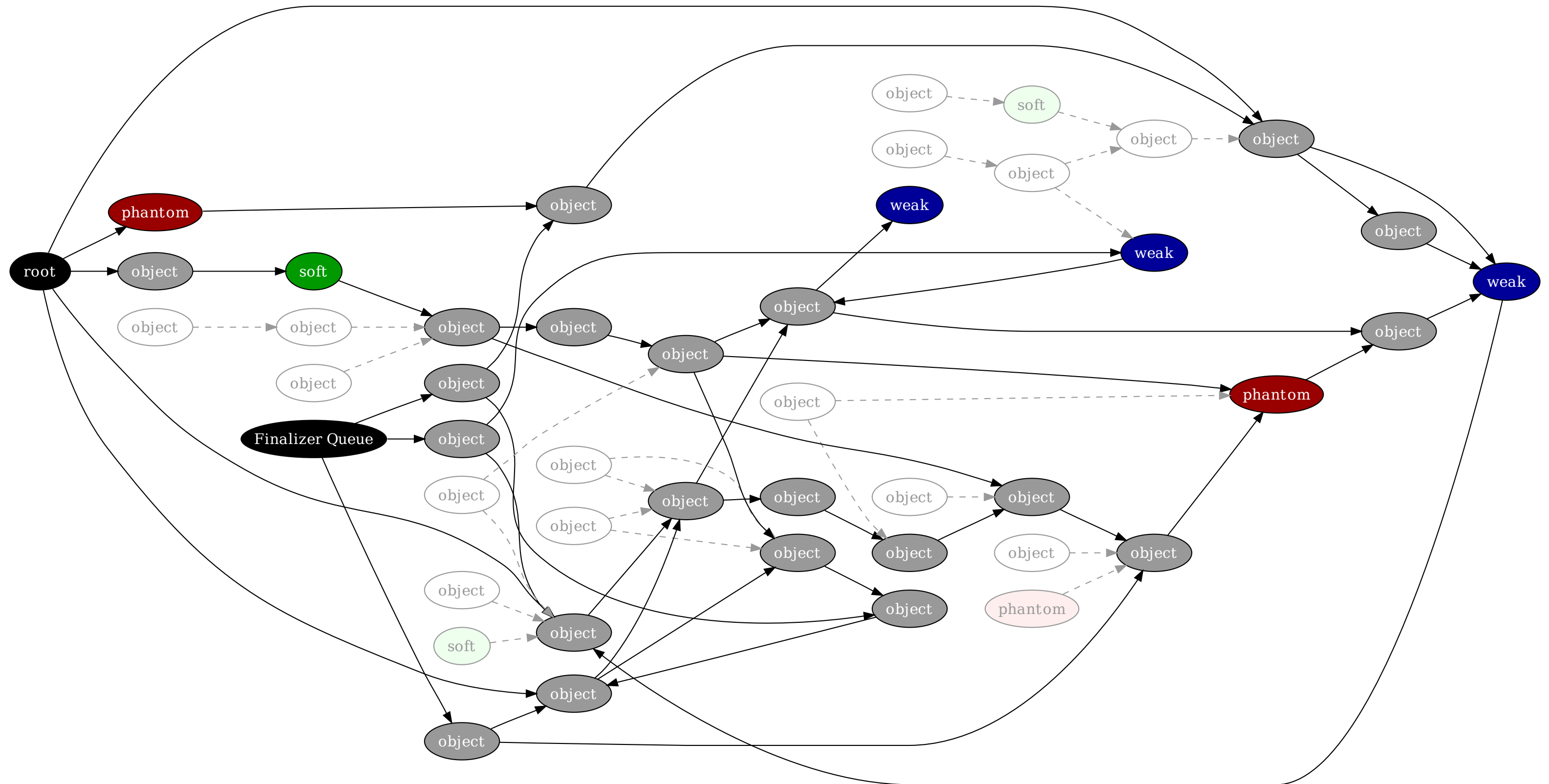
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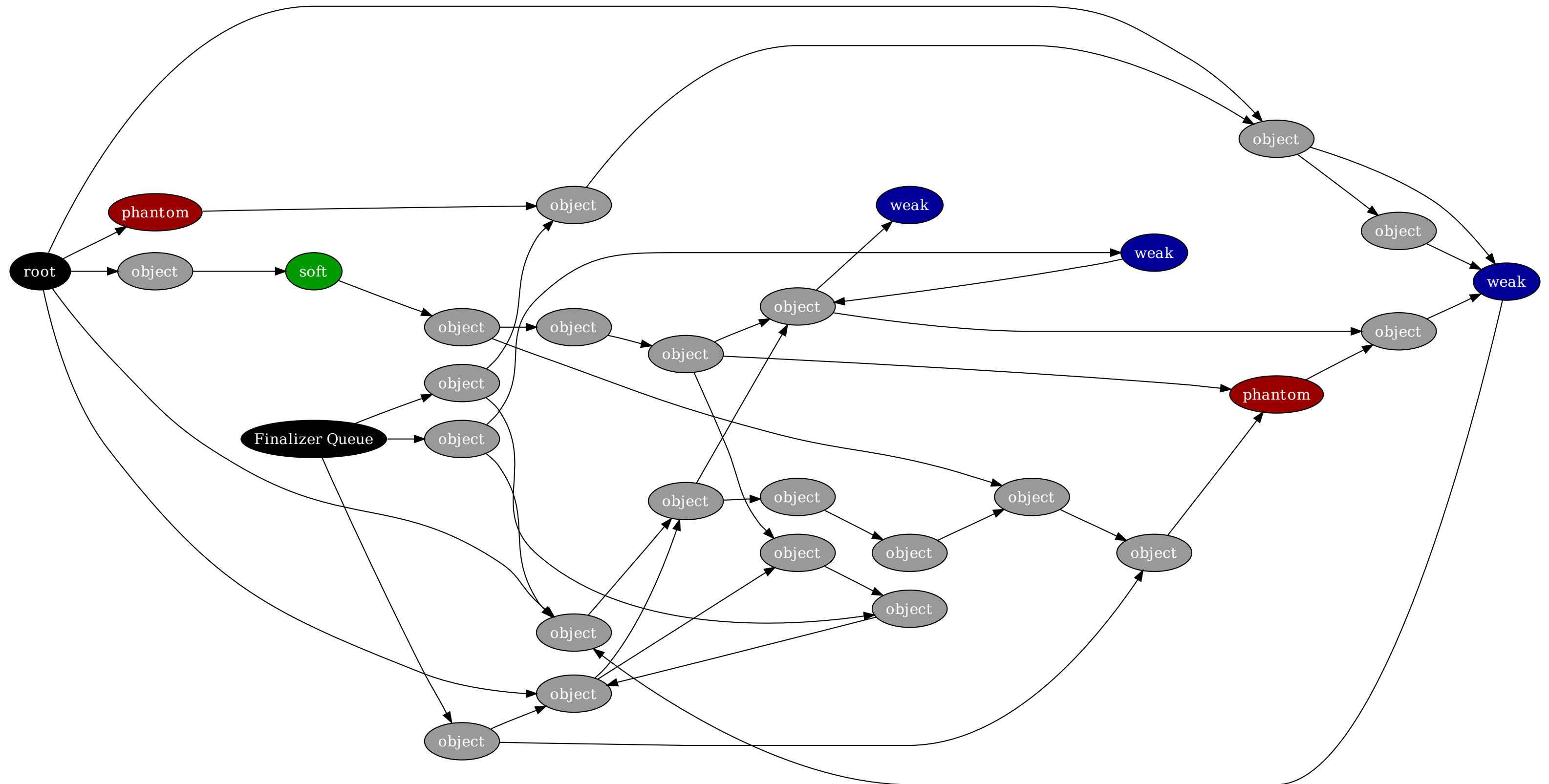
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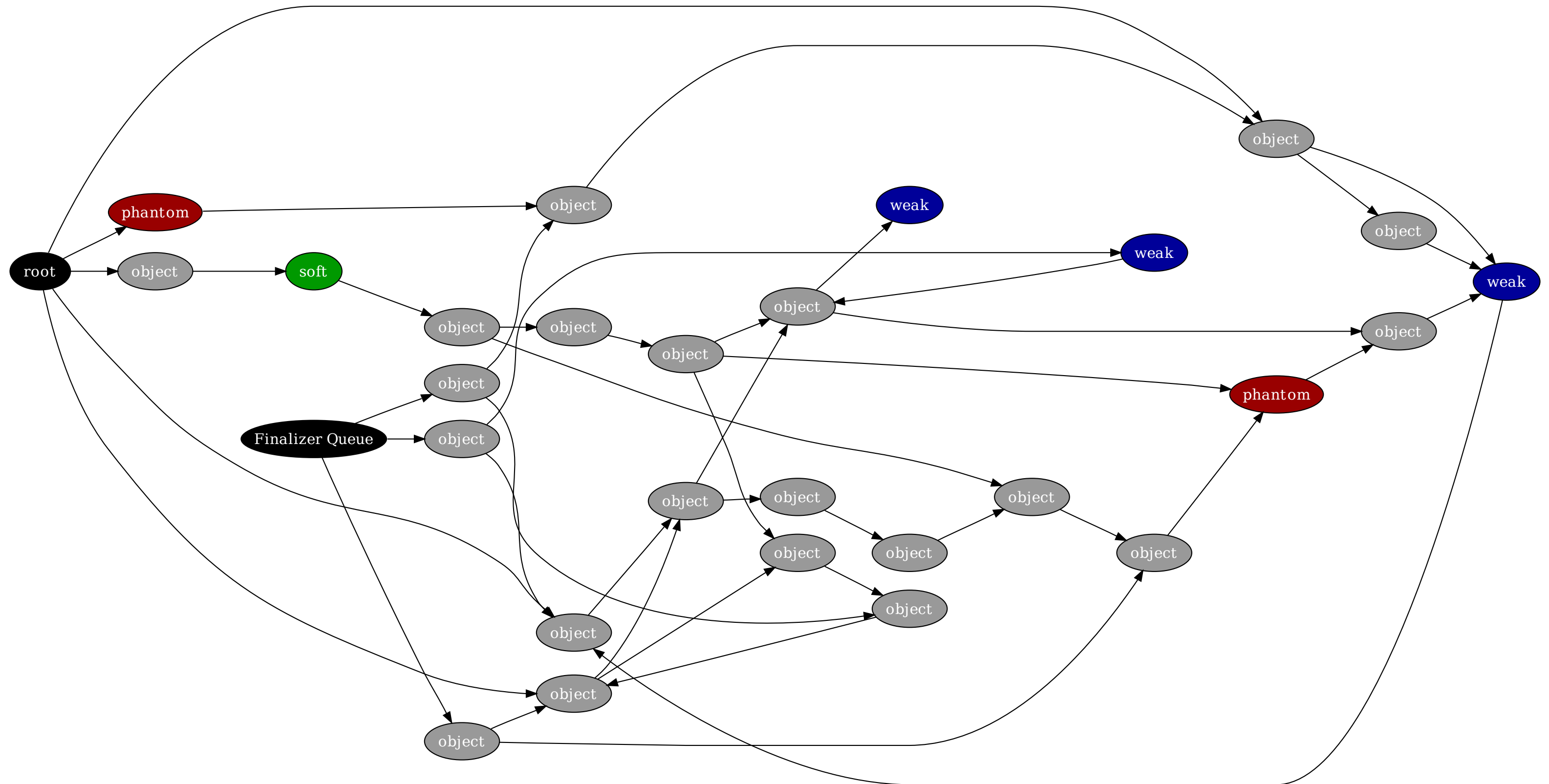
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10. Repeat.



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.



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Thank You

