BlinkGC 101

keishi@

2020-03-18

Trivia Quiz

How many memory allocators does Chrome use?

Trivia Quiz

How many memory allocators does Chrome use?

Answer: Too Many!

- PartitionAlloc
- BlinkGC
- V8
- malloc
  - (Win/Mac) System allocator
  - (Android) jemalloc/dlmalloc
  - (Linux/Cros) Tcmalloc
- (Android) Java

BlinkGC 101

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Contents

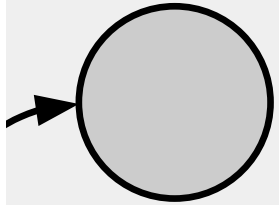
- What is Tracing GC?
- How to use BlinkGC
- Advanced features

What is Tracing GC?

But before we get into that...

What is reference counting?

- Every object has a “reference count”
- Use smart pointers to count the number of retaining references (e.g. `std::shared_ptr`, `base::scoped_refptr`)
- When the count reaches zero, the object is deallocated
- Very common automatic memory management
  - non-Blink chrome code use it
  - Blink used to use it



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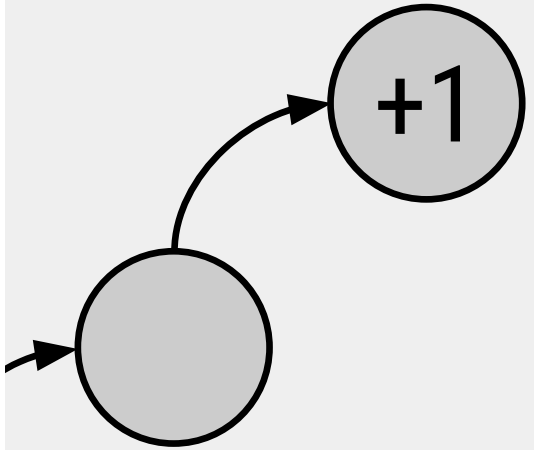

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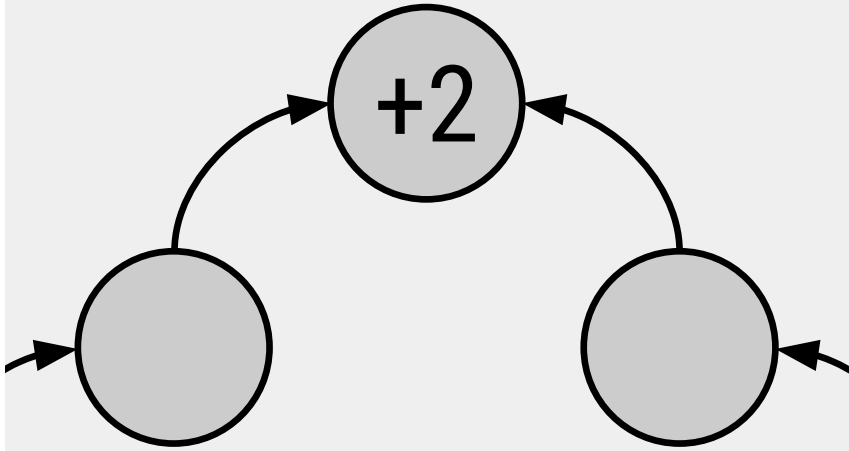

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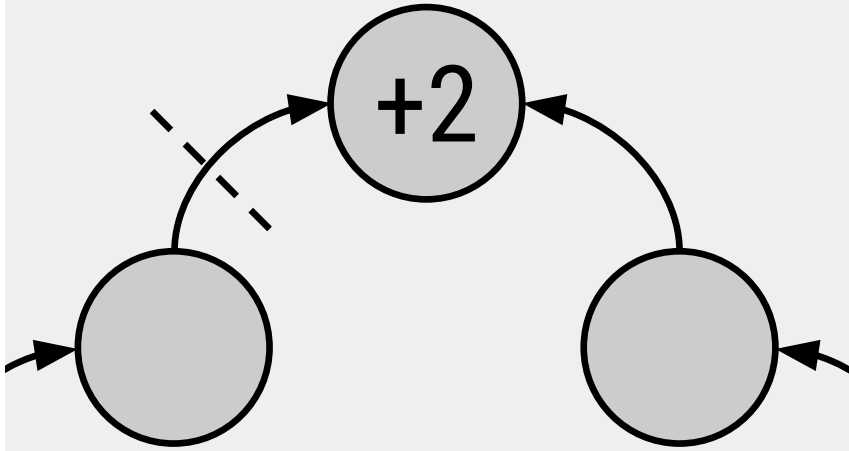

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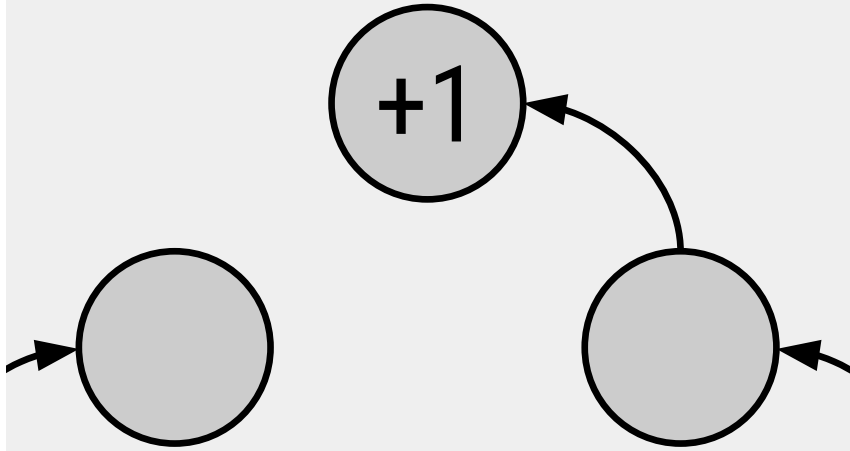

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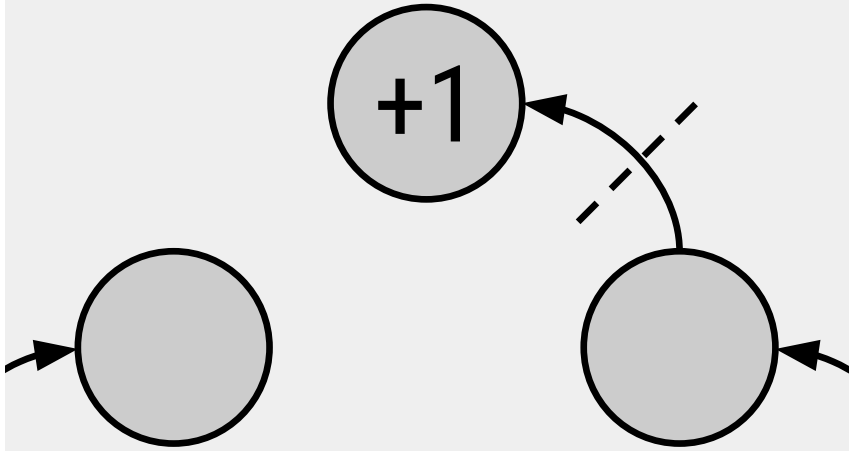

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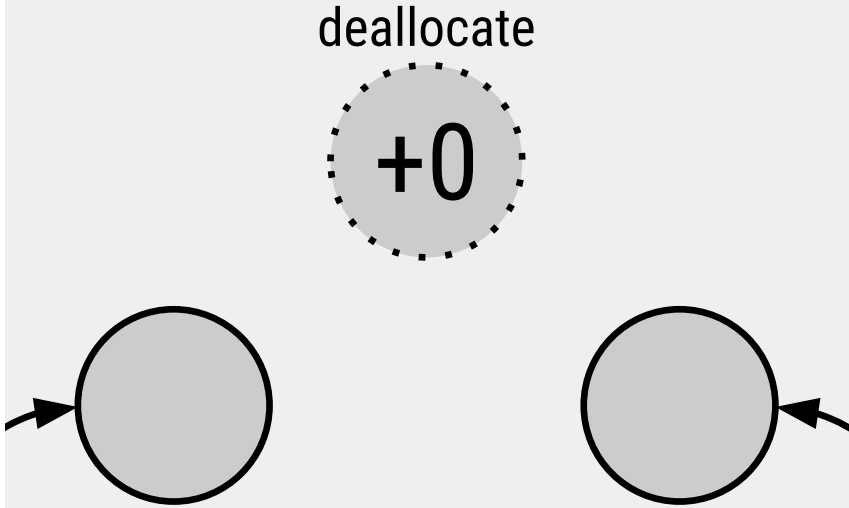


Problems with reference counting

Memory Leak

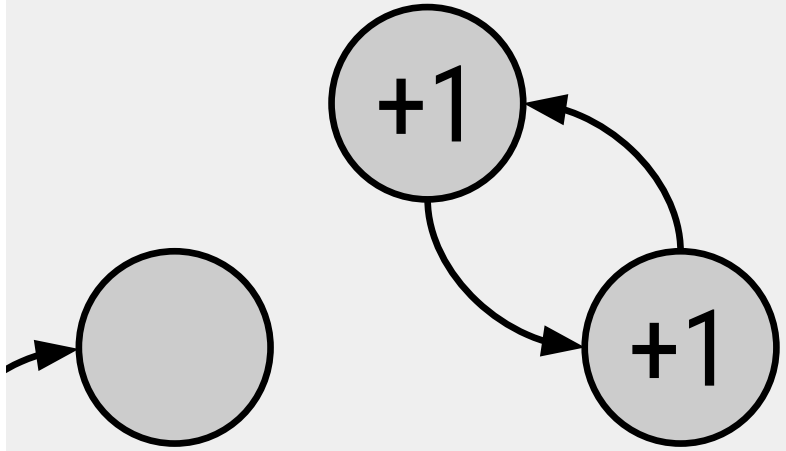
Reference cycles cannot be collected and cause memory leaks.

Need to use dangerous raw pointers

Raw pointers must be used to avoid reference cycles or reduce reference counting overhead.

V8 uses garbage collection

Blink needs to interoperate. Also user JS can create reference cycles.



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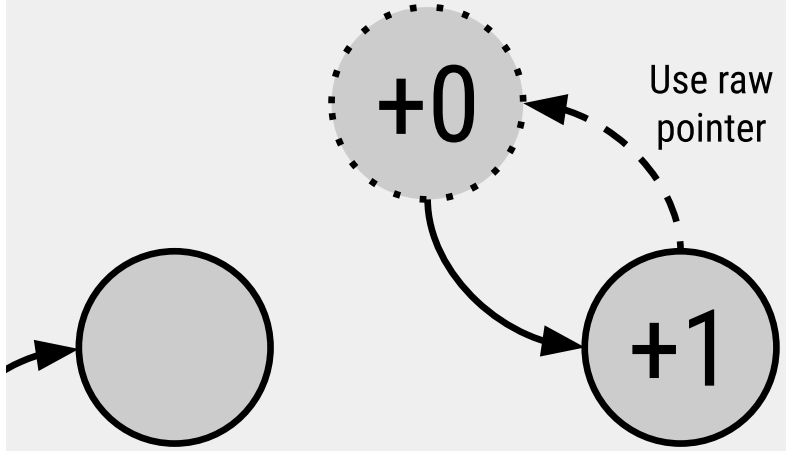

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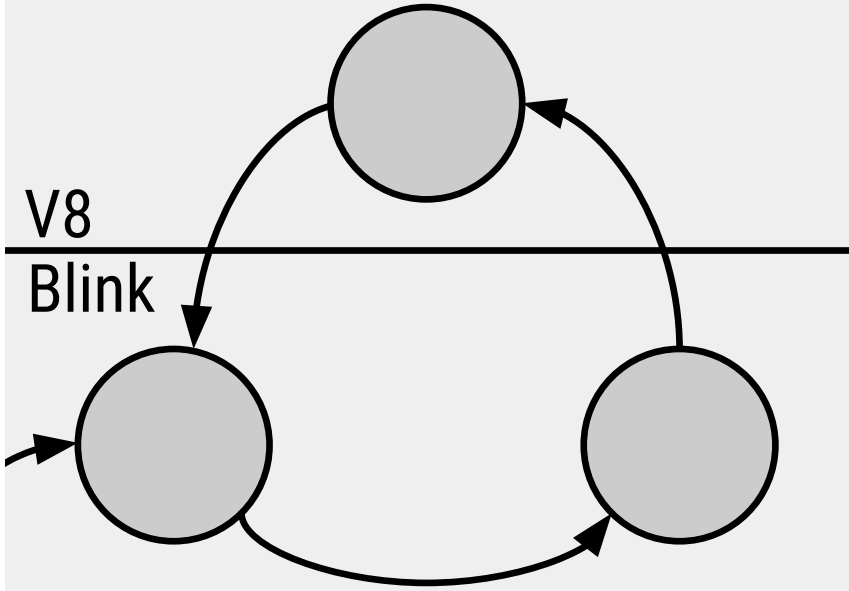
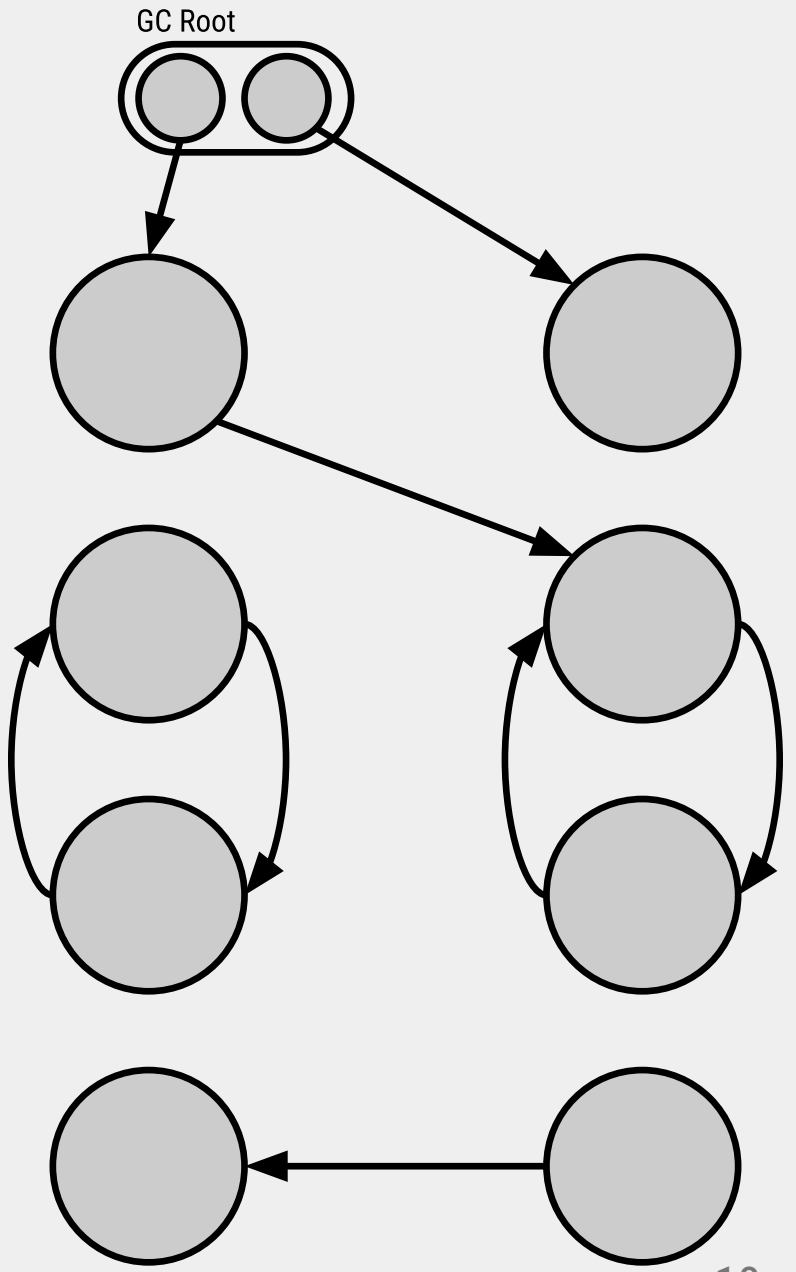


So in 2012, haraken started the **Oilpan project**...

And thus a mark & sweep Tracing GC was implemented...

How tracing GC works

- Objects and the reference between them form a graph called **object graph**.
- We start from the **GC root** and traverse the object graph. Marking reachable objects.
- When we are done marking, we sweep away all the unmarked objects and free that memory.
- Note how reference cycles were successfully collected 😄



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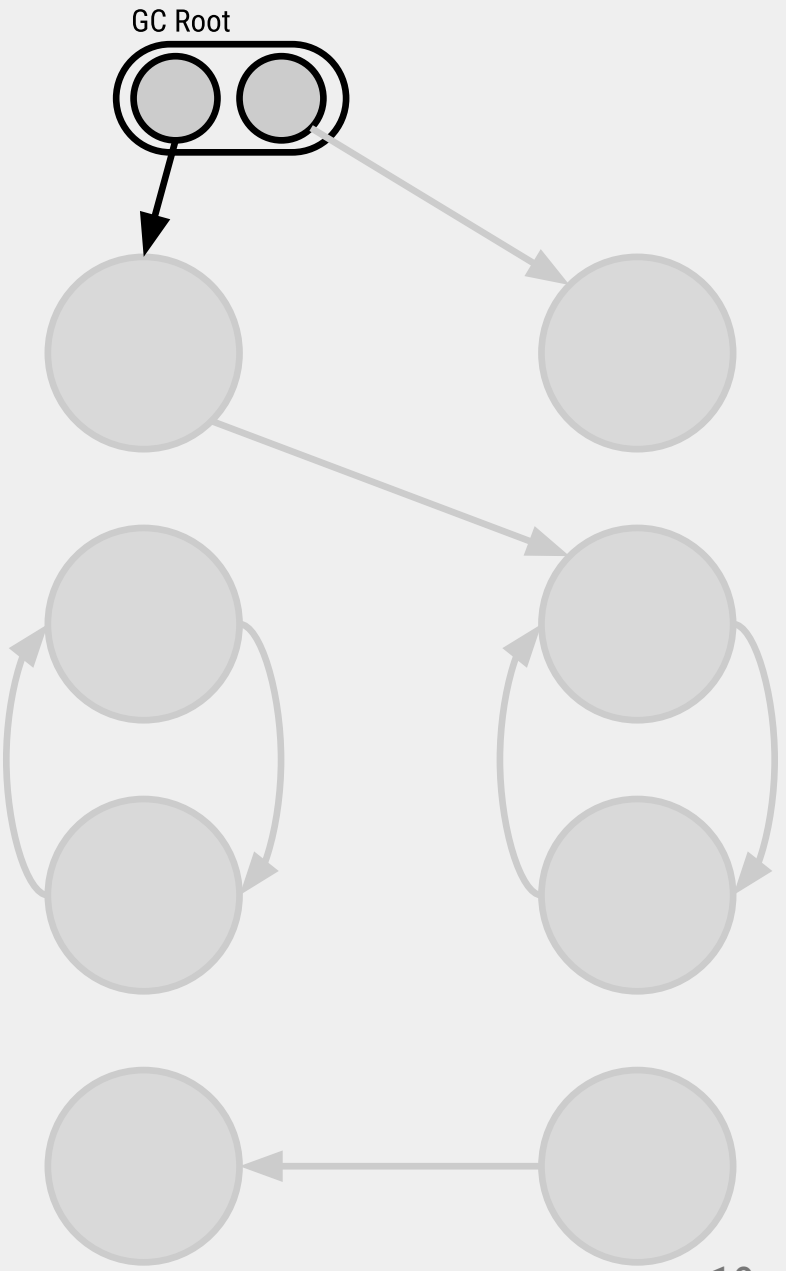

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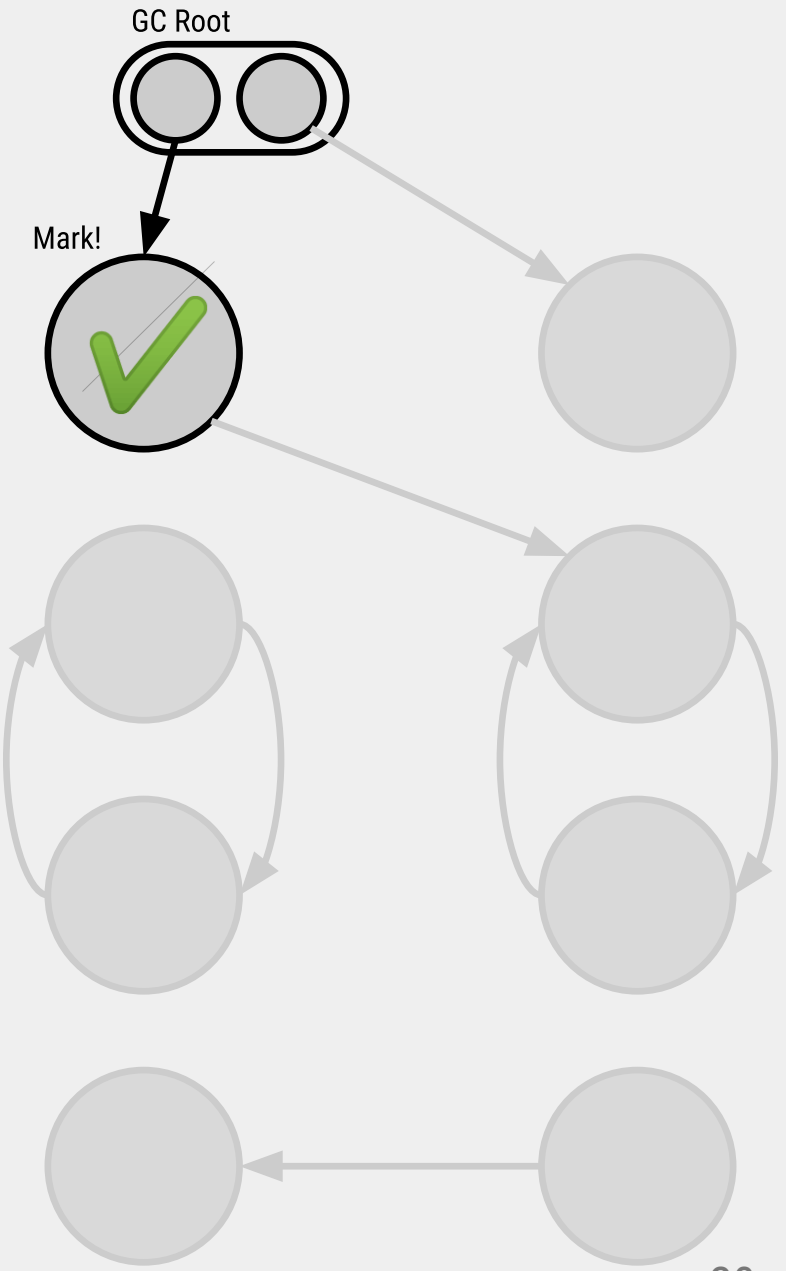

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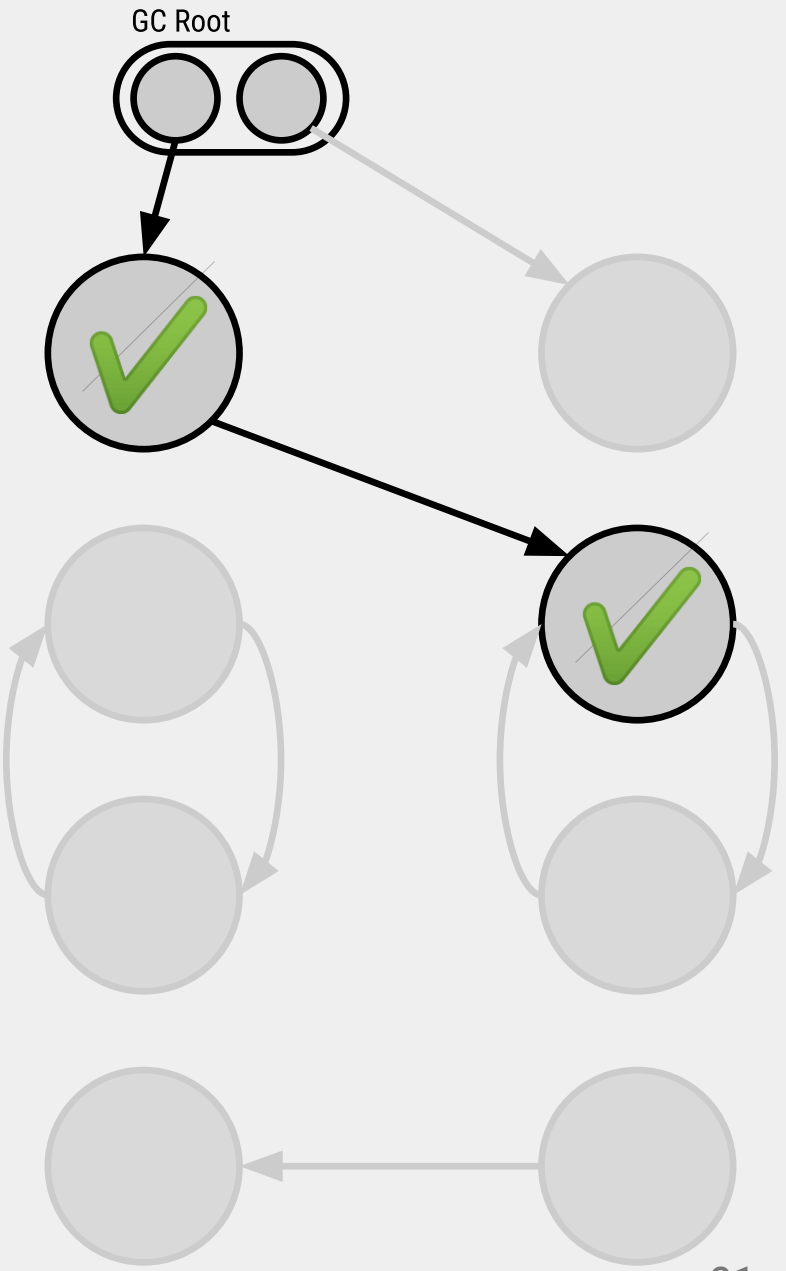

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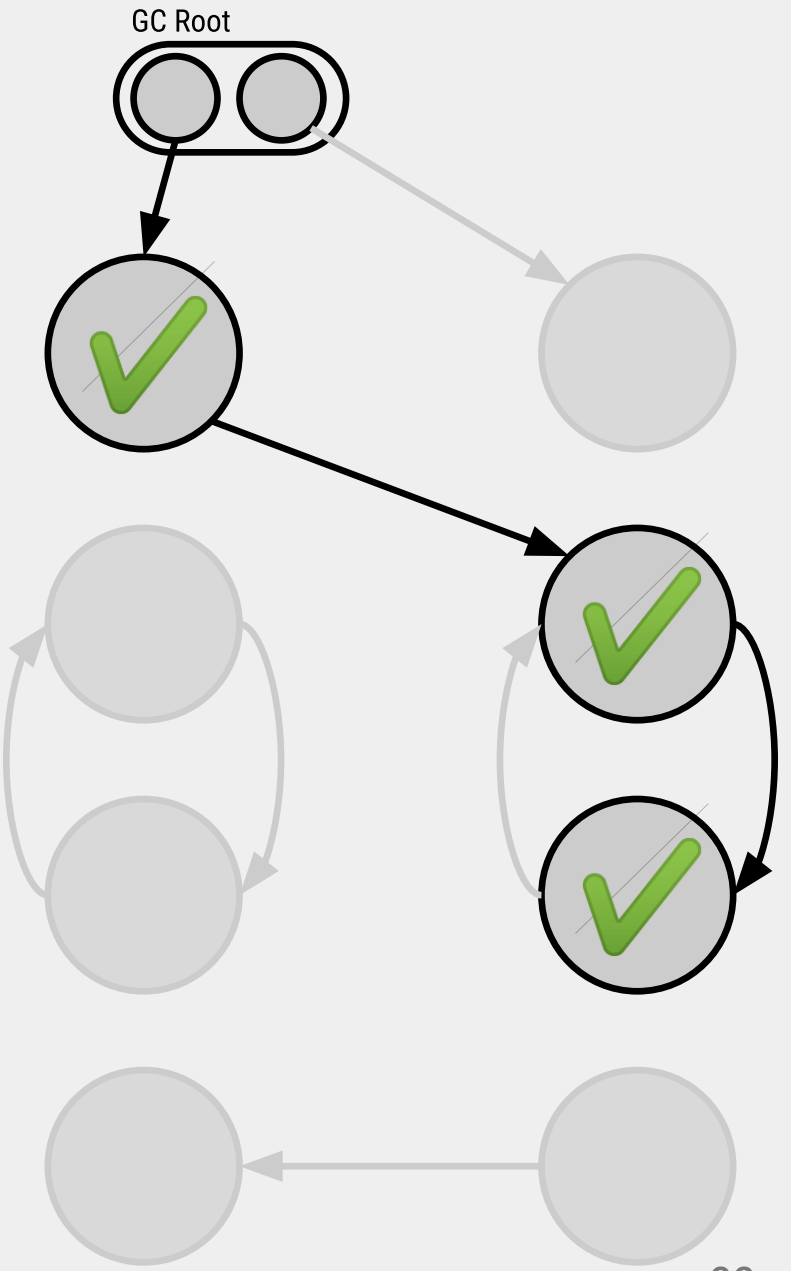

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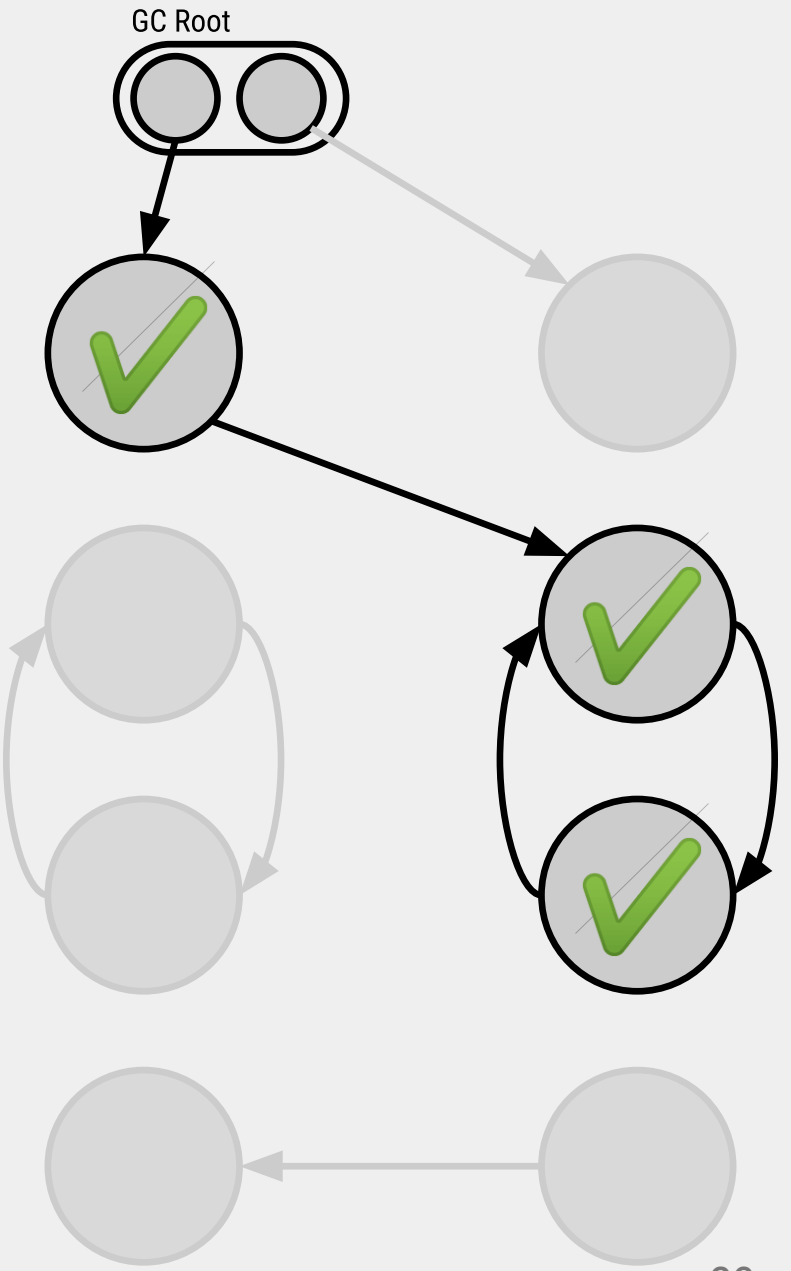

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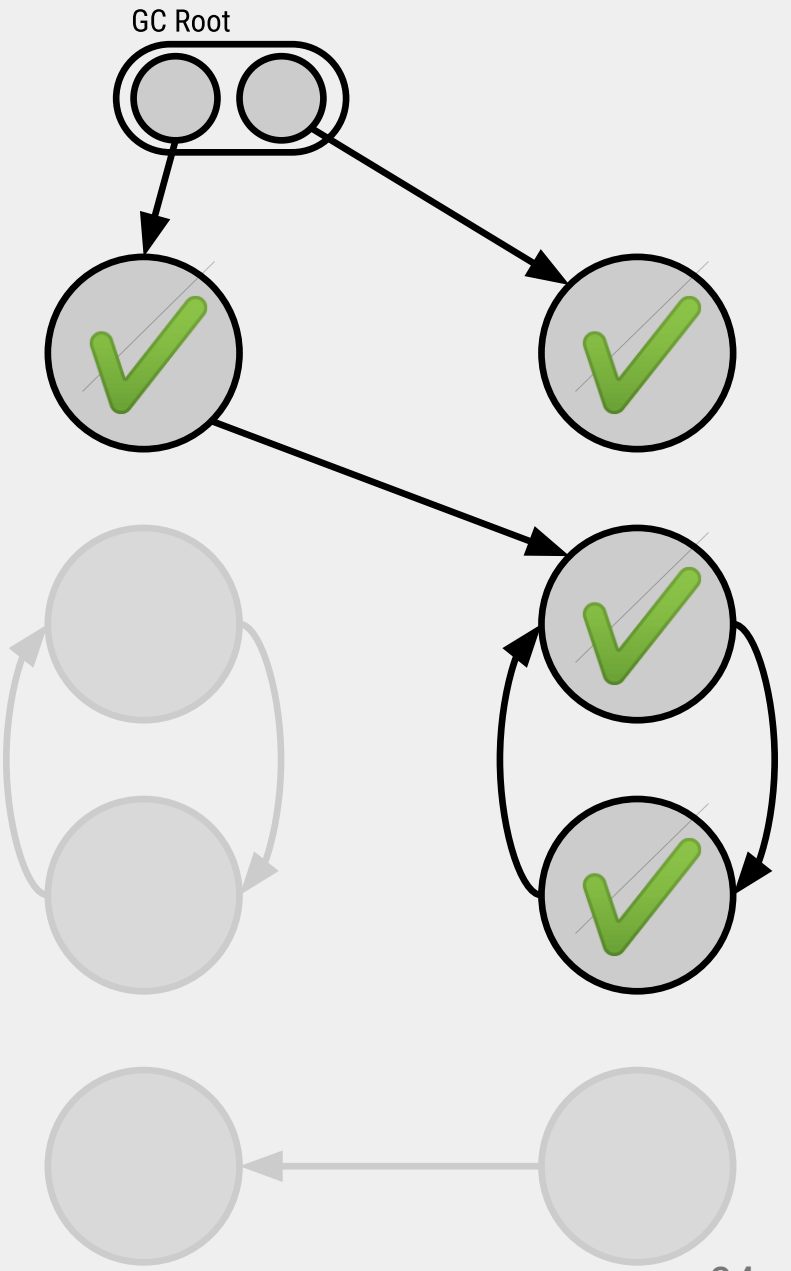

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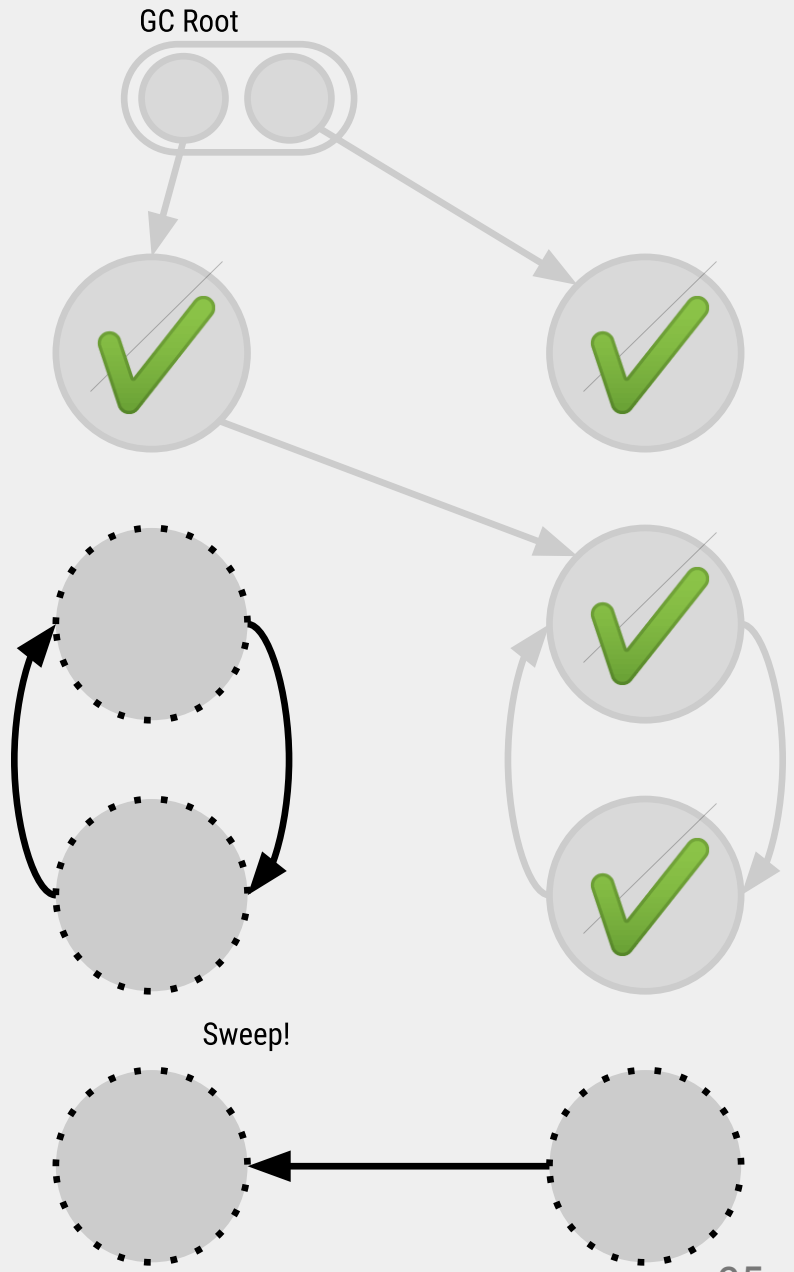

Tracing GC - Pros

- No ~~raw pointers~~ unmanaged references
- No use after free bugs
- No reference cycle memory leaks
- Unified V8/Blink heap means fully spec compliant and no leaks
- No reference counting overhead
- Debug memory leaks using the heap profiler

Tracing GC - Cons

- Pause time
  - We need to stop execution to traverse the object graph
  - This will add jank (dropped frames)
  - But the pause time has been minimized by implementing advanced GC algorithms
- Finalizers are harder to write
  - Order of finalization is not guaranteed

How to use BlinkGC

How to implement GC in C++

1. ~~use special memory layout ala V8~~ (We have existing C++ code base)
2. ~~use conservative scanning ala Boehm GC~~ (We want precise GC)
3. ~~use special compiler ala C++/CLI~~ (Windows Chrome used to use Visual C++. GCC is used unofficially)

→ BlinkGC uses regular C++ with additional rules enforced through a clang plugin

BlinkGC specific terminology

Oilpan = project codename

BlinkGC or **heap** = name in code

	Class	Object (i.e. class instance)
... that uses Oilpan	**garbage-collected**	**on-heap object**
... that doesn't use Oilpan	**non-garbage-collected**	**off-heap object**

persistent = V8 originated term for GC root

finalizer = destructor

How to create a GarbageCollected class

1. inherit `GarbageCollected<T>`
2. add a `Trace()` method

```
#include "platform/heap/garbage_collected.h"

class MyClass : public GarbageCollected<MyClass> {
 public:
  void Trace(Visitor*) {}
  // ...
};
```

GC basically calls `Trace()` method recursively to mark all reachable objects.

Allocating allocate a GarbageCollected class

Must not use `new T()`.

Must use `MakeGarbageCollected<T>(Args&&...)`.

Think of it like `std::make_unique<T>()` for GCed classes.

```
element_ = MakeGarbageCollected<HTMLDivElement>(document);
```

How to reference an on-heap object

We have **three** ways of referencing an on-heap object.

1. Reference from on-heap object to on-heap object

1. Use `Member<T>` handle
2. Don't forget to add it to the `Trace()` method

```
#include "platform/heap/member.h"

class MyClass : public GarbageCollected<MyClass> {
 public:
  void Trace(Visitor* visitor) {
    visitor->Trace(element_);
  }
  // ...
 private:
  Member<HTMLElement> element_;
};
```

References will traced by calling the `Trace()` method.

2. Reference from stack memory to on-heap object

1. Use a raw pointer
2. ... no need to trace

```
MyClass* CalculateFoo(HTMLElement* element) { // OK!
  MyClass* bar = MakeGarbageCollected<MyClass>(); // OK!
  // ...
  return bar; // OK!
}
```

References will be found automatically by scanning the stack memory.

3. Reference from off-heap object to on-heap object

1. Use `Persistent<T>` handle
2. ... no need to trace

```
#include "platform/heap/persistent.h"

class MyClass {
  // ...
 private:
  Persistent<HTMLElement> element_;
};
```

References will be a GC root and traced automatically.

Beware! If you use `Persistent`, you can create reference cycles and leak memory.

(Recap) How to reference an on-heap object

1. From on-heap object: use `Member<T>` (and add to `Trace()`)
2. From stack memory (i.e. function body): use raw pointer `T*`
3. From off-heap object: use `Persistent<T>`

Heap collections

We have GCed variants for a bunch of collections. Just add the "Heap" prefix!

- `Vector` → `HeapVector`
- `HashSet` → `HeapHashSet`
- `HashMap` → `HeapHashMap`

```
#include "platform/heap/heap_allocator.h"

class MyClass : public GarbageCollected<MyClass> {
 public:
  void Trace(Visitor* visitor) {
    // Heap collections need to be traced.
    visitor->Trace(elements_);
  }
  // ...
 private:
  HeapVector<Member<HTMLElement>> elements_;
};
```

Weak references

Use `WeakMember` or `WeakPersistent`.

They will automatically become `nullptr` when the object becomes garbage.

This rewrite happens in the GC atomic pause, right after the marking phase.
Do a null check => if the reference is available, you can use that object normally.

Advanced features

Inheriting a GarbageCollected class

Base classes must be traced

```
class MyBaseClass : public GarbageCollected<MyBaseClass> {/*...*/};
class MyClass : public MyBaseClass {
  void Trace(Visitor* visitor) {
    MyBaseClass::Trace(visitor);
  }
};
```

You cannot inherit multiple GCed classes

If you want to do multiple inheritance, use `GarbageCollectedMixin`

Multiple Inheritance: GarbageCollectedMixin

A non-leftmost base class of a garbage-collected class should derive from `GarbageCollectedMixin`.

A class deriving from `GarbageCollectedMixin` can be treated similarly as garbage-collected classes.

- it can use `Member<T>` and `WeakMember<T>` fields
- it should have a `Trace()` method
- it can be referenced using all the usual handles, such as `Member<T>` or `Persistent<T>`
- subclass's `Trace()` method must call each mixin base class's `Trace()` method

Multiple Inheritance: How to use GarbageCollectedMixin

- inherit `GarbageCollectedMixin`
- to inherit a mixin class , you must add the macro `USING_GARBAGE_COLLECTED_MIXIN(T)`

```
class MyBaseClass : public GarbageCollected<MyBaseClass> {};
class MyMixinClient : public GarbageCollectedMixin {
  virtual void Trace(Visitor* visitor) { visitor->Trace(element_); }
 public:
  Member<HTMLElement> element_;
};

class MyClass : public MyBaseClass, public MyMixinClient {
  USING_GARBAGE_COLLECTED_MIXIN(MyClass);
  void Trace(Visitor* visitor) override {
    MyBaseClass::Trace(visitor);
    MyMixinClient::Trace(visitor);
  }
};
```

Multiple Inheritance: Leftmost derivation rule

Base class inheriting `GarbageCollected` must come first.

```
class MyBaseClass : public GarbageCollected<MyBaseClass> {/*...*/};
class MyMixinClient : public GarbageCollectedMixin {/*...*/};

class MyClass : public MyBaseClass, public MyMixinClient {/*...*/};
class BadClass : public MyMixinClient, public MyBaseClass {/*...*/}; // BAD
```

This rule is needed to assure each on-heap object has its own canonical address.

Multi Threading

BlinkGC is run independently on each thread.

Every on-heap object is owned by the thread where it was allocated.

`Member` cannot be used to reference an object owned by another thread.

To do so, you must use `CrossThreadPersistent<T>` and `CrossThreadWeakPersistent<T>`.

But beware, just as with Persistent, they can cause reference cycles.

STACK_ALLOCATED

If a class is only ever going to be used on the stack, you can skip using `Member` and just use raw pointers. You also don't need to write a `Trace()` method.

To do this, add the `STACK_ALLOCATED` macro to your class.

```
class ConstructionStackScope {
  STACK_ALLOCATED();

  // OK: no Trace() method
  private:
  HTMLElement* element_; // OK: raw pointer
};

void Foo() {
  ConstructionStackScope scope;
  // ...
}
```

DISALLOW_NEW

Sometimes a class is allocated inline as part of an on-heap object.

It sometimes makes a cleaner interface and saves you a pointer dereference.

This class can also be allocate on stack.

```
class NodePointer {
  DISALLOW_NEW();
 public:
  void Trace(Visitor* visitor) { visitor->Trace(node); }
  Member<Node> node;
};

class NodeIterator final : public GarbageCollected<NodeIterator> {
 public:
  void Trace(Visitor* visitor) { visitor->Trace(reference_node_); }
 private:
  NodePointer reference_node_;
};
```

Finalizer 

Class destructors will be run as finalizers.

```
class MyClass final : public GarbageCollected<MyClass> {
 public:
  ~MyClass() {
    LOG(ERROR) << "FINALIZER";
  }
  void Trace(Visitor* visitor) {}
};
```

- Destructor must not touch other on-heap objects.
  - Finalizers are executed in random order.
  - The reference from Member may already be destroyed.
- Destructor must be `virtual` if the class is not `final`.

Pre finalizer 🍅🍅🍅

Special finalizer called right after the marking phase in the atomic pause.

Incurs performance penalty. Avoid if at all possible.

```
class MyClass : public GarbageCollected<MyClass> {
  USING_PRE_FINALIZER(MyClass, Dispose);
public:
  void Dispose() {
    // OK: Other on-heap objects can be touched in a pre-finalizer.
    other_->Dispose();
  }

  ~MyClass() {
    // BAD: Not allowed.
    // other_->Dispose();
  }

private:
  Member<OtherClass> other_;
};
```

Finalizer vs pre finalizer

	finalizer	**pre finalizer**
timing	delayed	in atomic pause
touch other on-heap objects	NO	YES
allocate new on-heap objects	YES	NO
clear references	YES	YES
performance impact	small	big

Please don't do complicated things in the finalizer or pre finalizer 🤦

Weak collection

- `HeapHashSet<WeakMember<T>>`
- `HeapHashMap<WeakMember<T>, Member<U>>` is equivalent to JS's `WeakMap`. Usually used to add data to T.
- `HeapLinkedHashSet<WeakMember<T>>`
- `HeapVector<WeakMember<T>>` is NOT allowed to avoid weak processing overhead to balloon.

Custom weak handling 🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅

You can set a callback to be called when the pointee gets garbage collected.

Beware that this is not called when the pointer and the pointee both get garbage collected,

UntracedMember 🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅
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GC_PLUGIN_IGNORE 🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅🍅
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Common Pitfalls (1)

Don't store raw pointers to on-heap objects

```
class MyClass : public GarbageCollected<MyClass> {
  int count_;
};
class NonGarbageCollected {
  // ...
private:
  MyClass* my_class_; // BAD!
  Vector<MyClass*> vector_; // BAD!

  // Storing reference to MyClass::count_
  int* my_class_counter_; // Also BAD! No iterior pointers
};
```

Bad even if the object is retained by some handle elsewhere.

On the stack, raw pointers are OK. Just don't store the raw pointers on heap memory.

Common Pitfalls (2)

Don't touch other on-heap objects in destructor

Explained in *Finalizer* slide.

Don't allocate garbage-collected classes on stack

```
void foo() {
  MyClass* bar = MakeGarbageCollected(MyClass); // OK
  MyClass baz; // BAD
}
```

Don't manually trigger GC in production code

Leave GC scheduling to the GC.

Conclusion

Imagine... a fully Oilpan world

- no use-after-free
- no reference cycle memory leaks
- its easy if you try...
- V8 and Blink working as one

Tokyo Architecture team is working on fully Oilpaned Blink

Munich V8 team is working on Oilpan infrastructure

🎉 Special thanks to the Crowdfunding Donors

 Yuki Shiino

 Adam

 Kentaro Hara

 Kenichi Ishibashi

 Tal Pressman

 Takuto Ikuta

 Hiroki Nakagawa

go/webshell

Apendix

PreciseGC vs ConservativeGC

PreciseGC

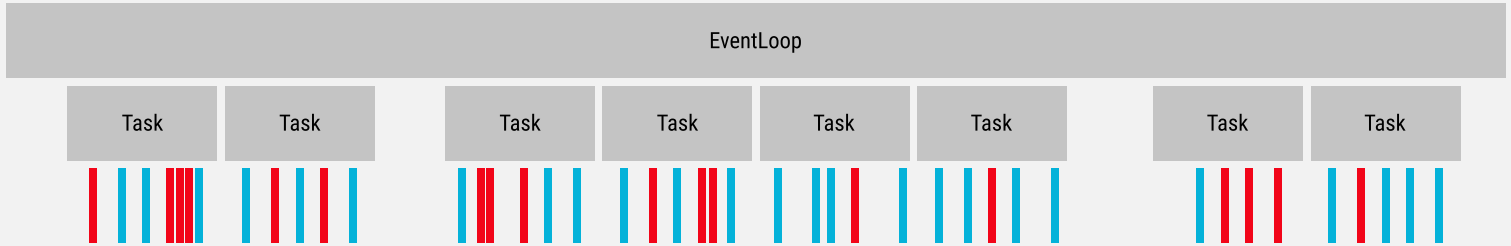
Runs as a task to guarantee that there are no on-heap object references on stack. Can collect all unreachable objects.

ConservativeGC

Runs inside allocations, when there is no free memory unless you GC. Scans the stack memory and traces any value that look like on-heap object references. May not be able to collect all unreachable objects.

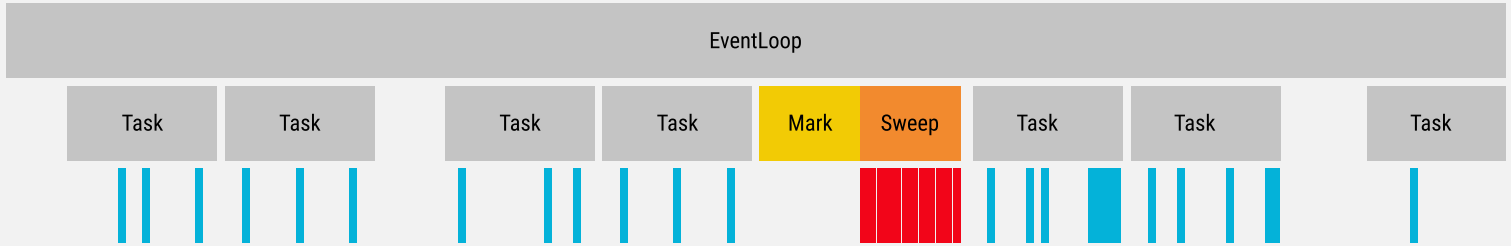
GC Phases (1)

In the reference counting days...



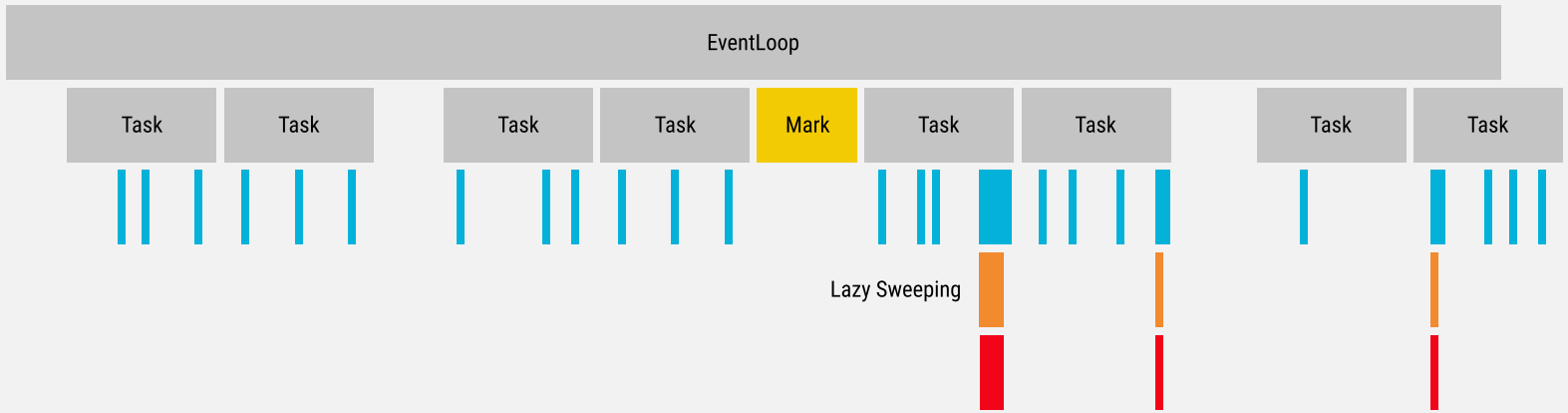
GC Phases (2)

Basic mark and sweep GC... but the pause time is a big down side



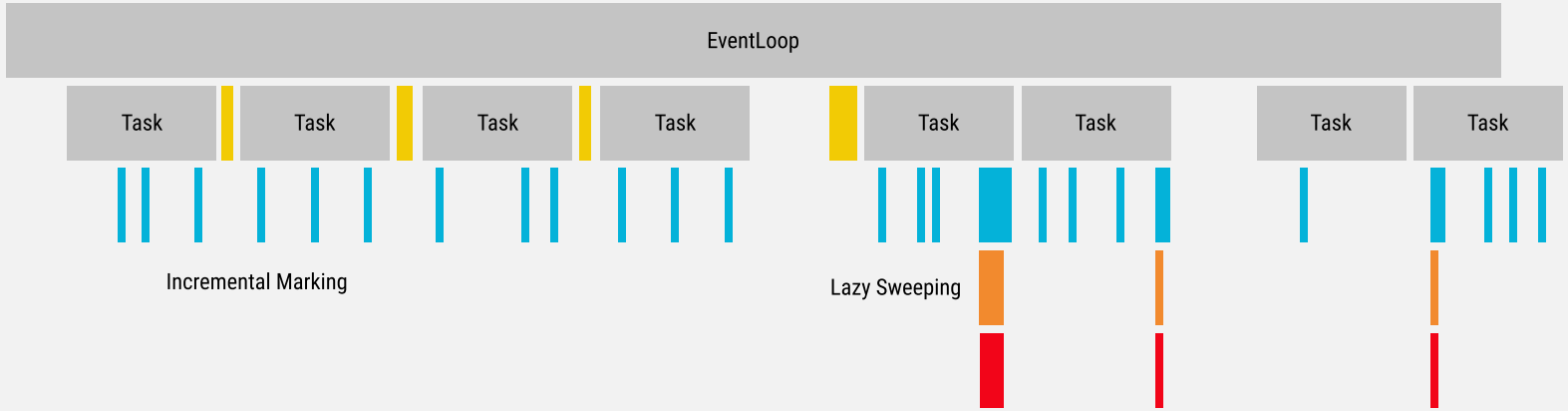
GC Phases (3)

We introduced many optimizations... Lazy Sweeping



GC Phases (4)

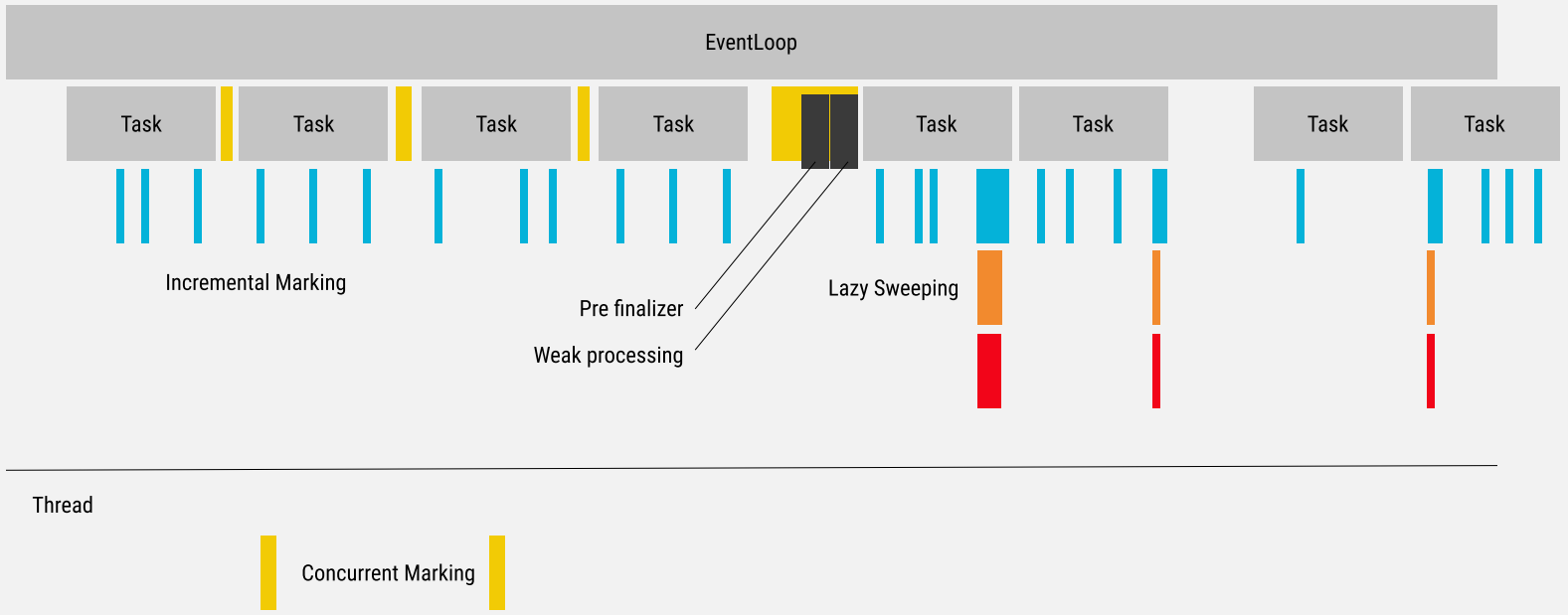
We introduced many optimizations... Incremental Marking



GC Phases (5)

We introduced many optimizations... Concurrent Marking

Pre finalizers and custom weak processing cannot be optimized



blink_gc_plugin warning examples

```
warning: [blink-gc] Class 'A' requires a trace method.
note: [blink-gc] Untraced field 'foo_' declared here:
warning: [blink-gc] Base class 'B' of derived class 'C' requires tracing.
warning: [blink-gc] Class 'D' contains invalid fields.
note: [blink-gc] std::unique_ptr field 'bar_' to a GC managed class declared here:
warning: [blink-gc] Class 'E' must derive from GarbageCollected in the left-most position.
```

BlinkGC in unit tests

To test behaviour around GC, trigger a GC using the following two ways

BlinkGC

```
ThreadState::Current()->CollectGarbage(
    BlinkGC::CollectionType::kMajor, BlinkGC::kNoHeapPointersOnStack,
    BlinkGC::kAtomicMarking, BlinkGC::kEagerSweeping,
    BlinkGC::GCReason::kForcedGCForTesting);
```

BlinkGC + V8 GC

```
V8GCController::CollectAllGarbageForTesting(v8::Isolate::GetCurrent());
```