.NET GC Internals

Mark phase

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(Non-Concurrent) Mark phase

.NET GC Internals Agenda

- Introduction - roadmap and fundamentals, source code, ...
- **Mark** phase - roots, object graph traversal, *mark stack*, mark/pinned flag, *mark list*, ...
- **Concurrent Mark** phase - *mark array/mark word*, concurrent visiting, *floating garbage*, *write watch list*, ...
- **Plan** phase - *gap*, *plug*, *plug tree*, *brick table*, *pinned plug*, *pre/post plug*, ...
- **Sweep** phase - *free list threading*, concurrent sweep, ...
- **Compact** phase - *relocate* references, compact, ...
- **Generations** - physical organization, *card tables*, ...
- **Allocations** - *bump pointer allocator*, free list allocator, *allocation context*, ...

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- **Q&A** - "but why can't I manually delete an object?", ...

02. .NET GC Internals - Mark phase

This module agenda:

- introduction
  - object graph
  - object graph traversal
- implementation
  - traversal
  - pin/mark flag
  - mark stack & mark list
  - vectorized mark list sorting "story"
- inside code .NET runtime 😍

Mark phase

We need to know which objects are "live"...

Object graph

In memory:

Object graph

In memory:

Type data:

```
record A(B b, D d);
record B(int X);
record C(B b, F f);
record D(E e);
record E(G g);
record F(int X);
record G(int Z);
```

Object graph

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Current "state":

```
var a = new A(..., ...);
var d = new D(...);
...we are here...
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Object graph

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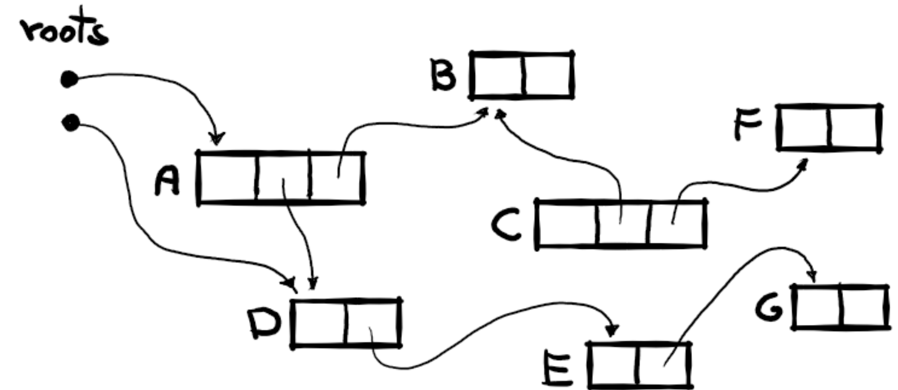
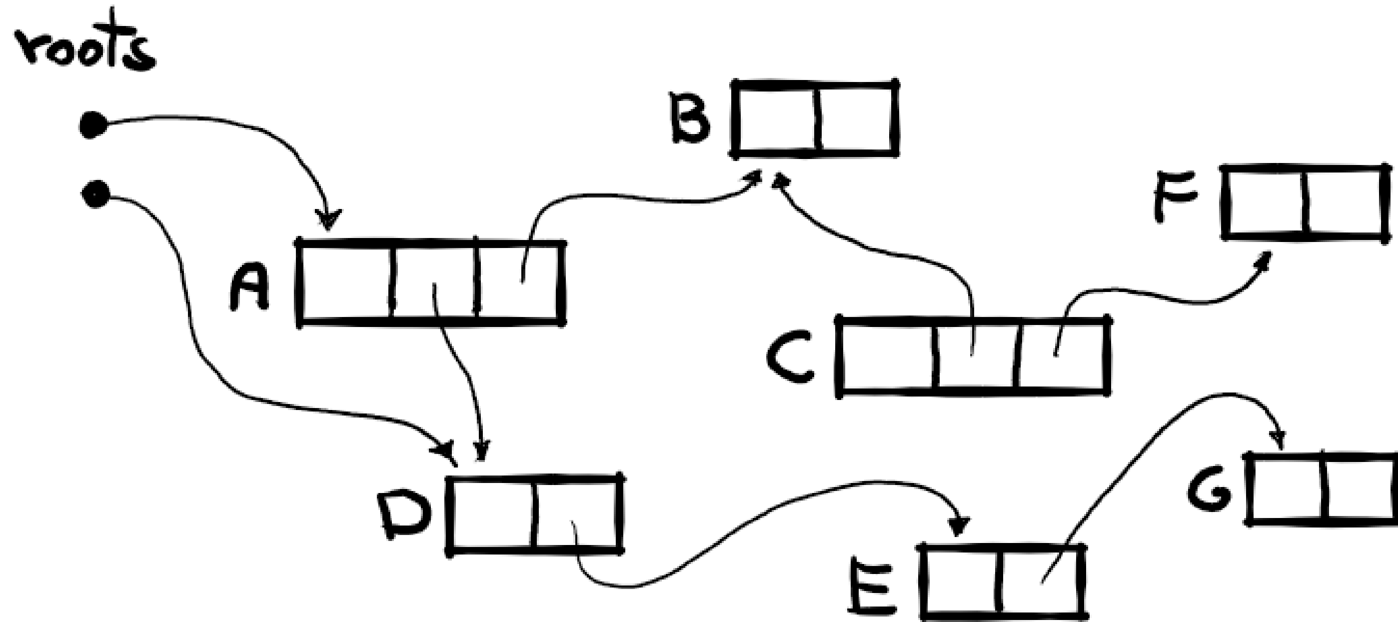
Object graph:



Object graph traversal



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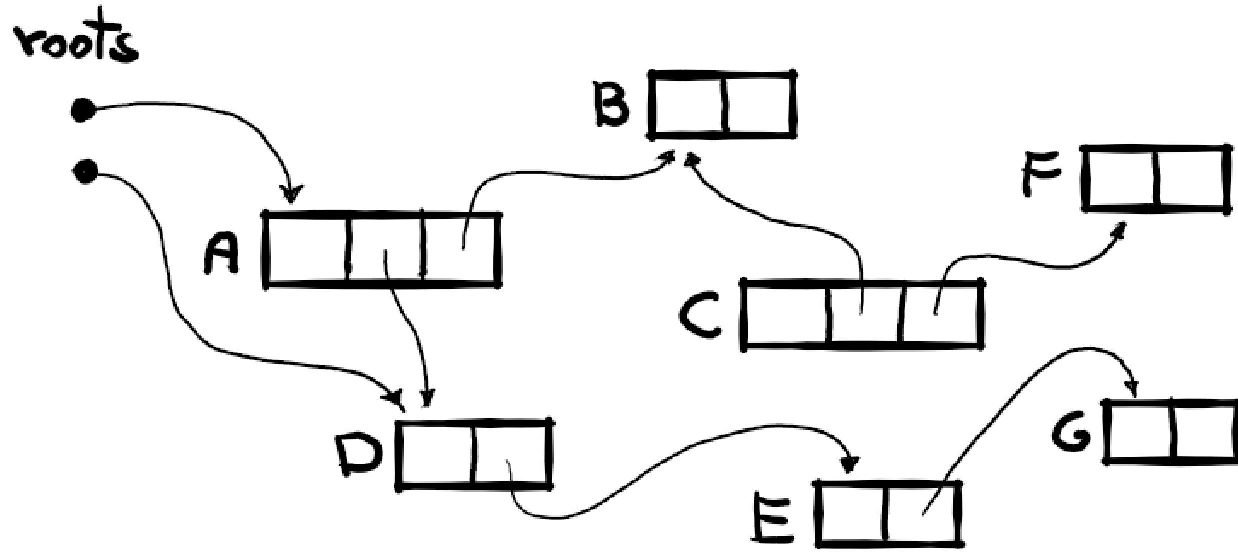
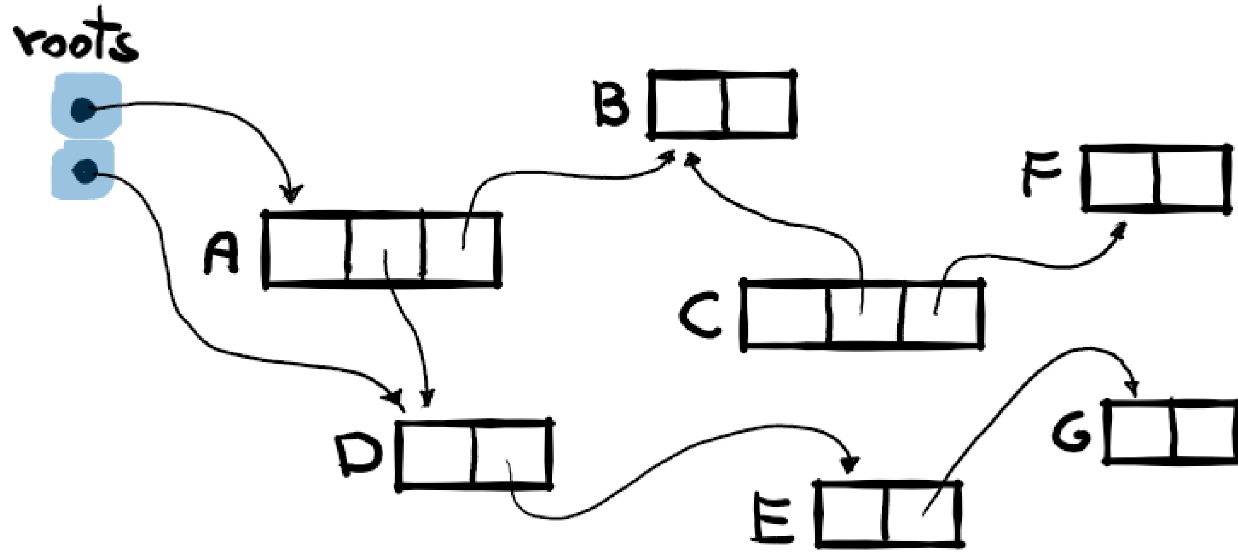


To visit:

Object graph traversal



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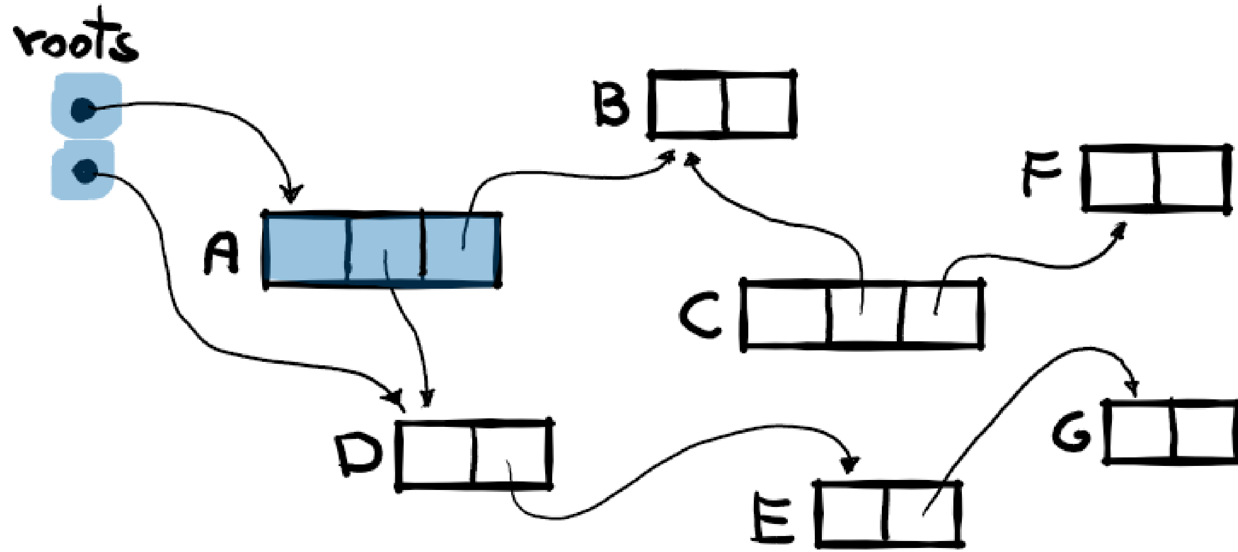
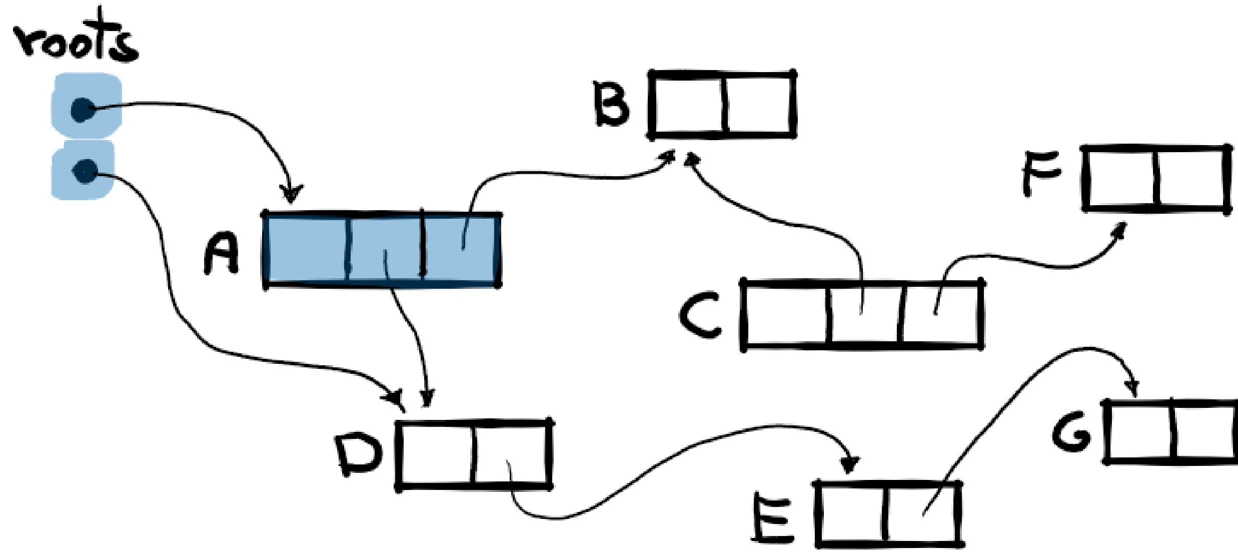


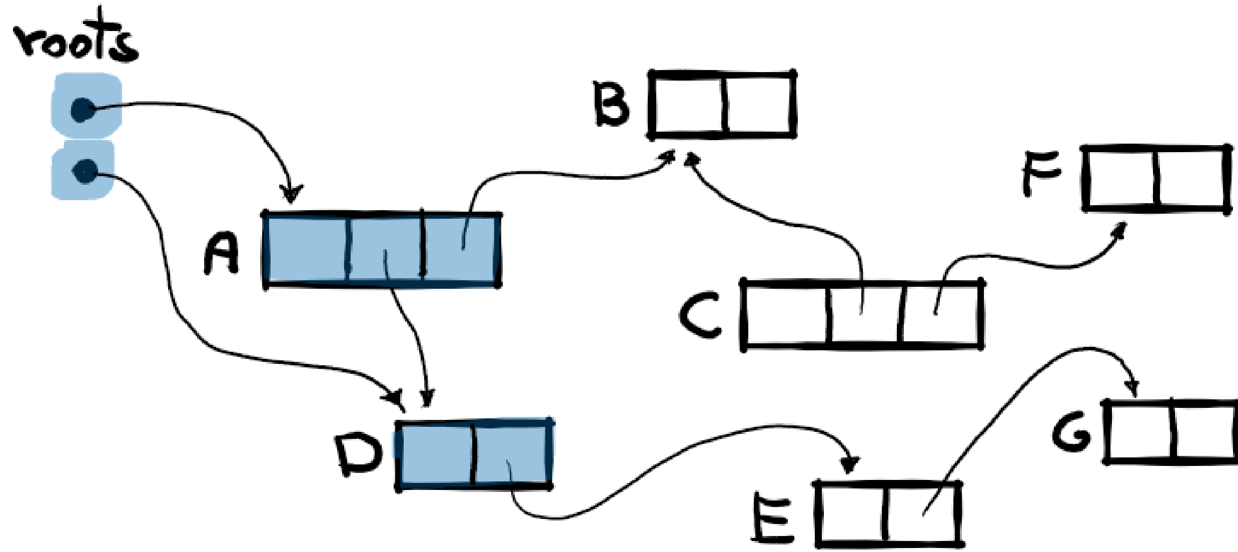
To visit: A, D, D, B

Object graph traversal



To visit: ~~A~~, D, D, B

Object graph traversal



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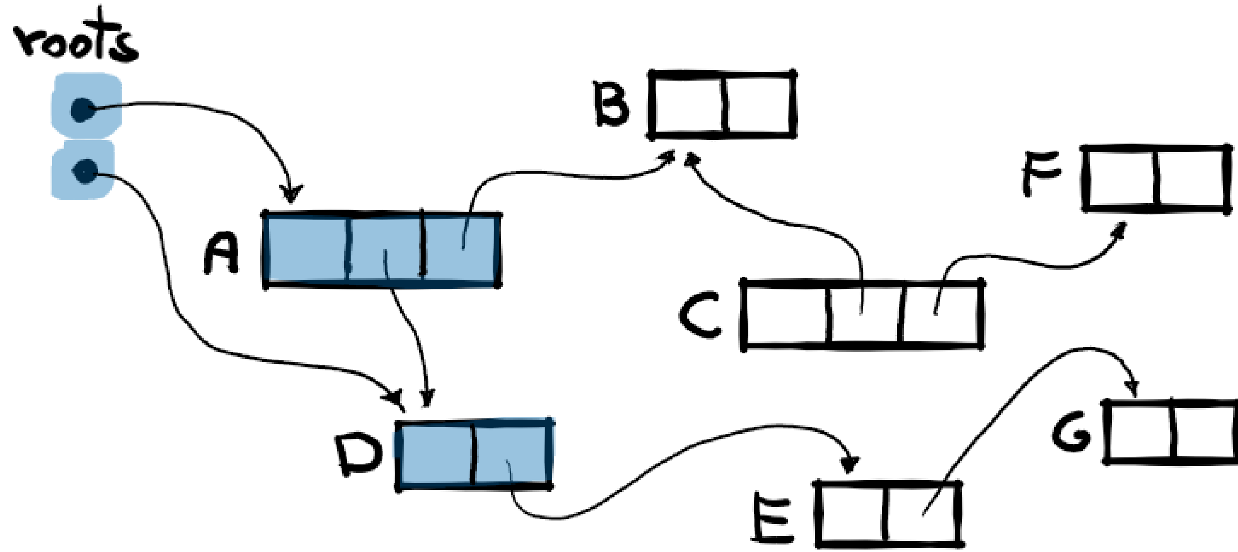

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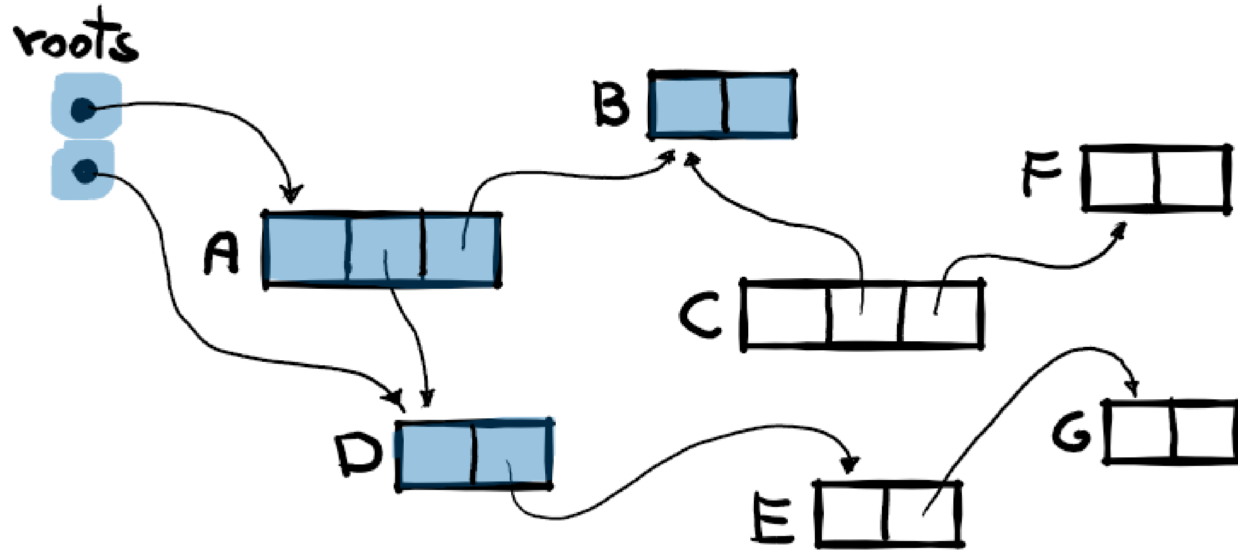

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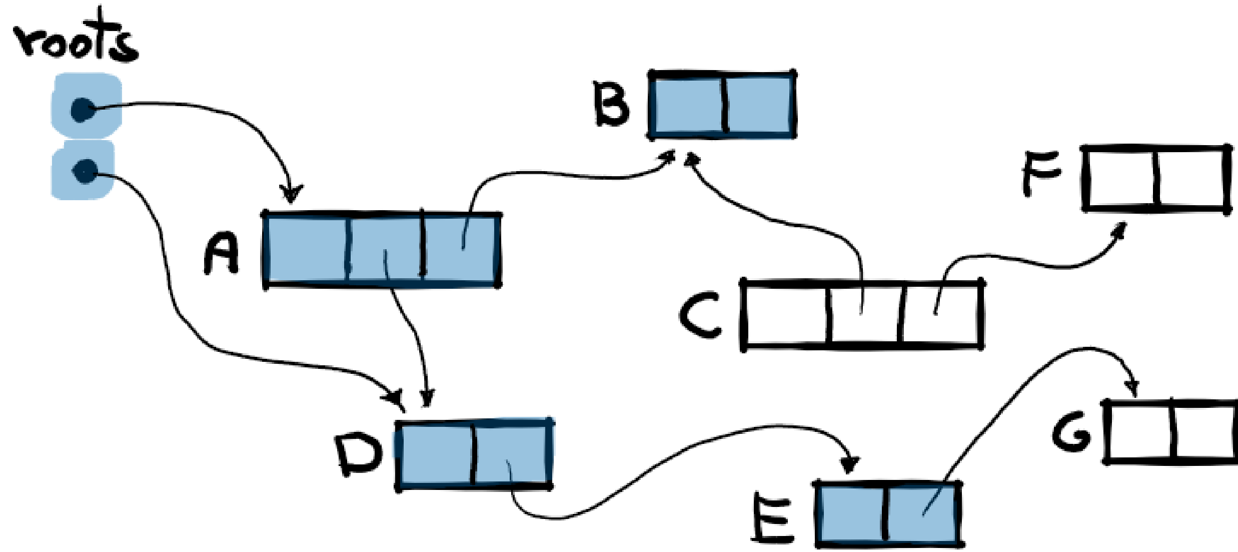

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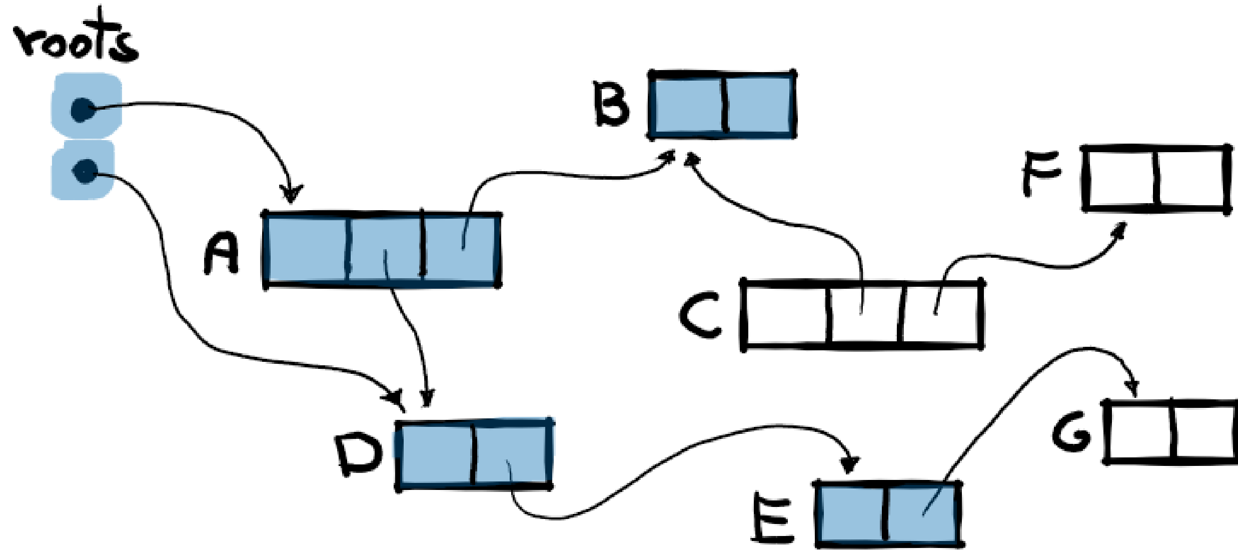

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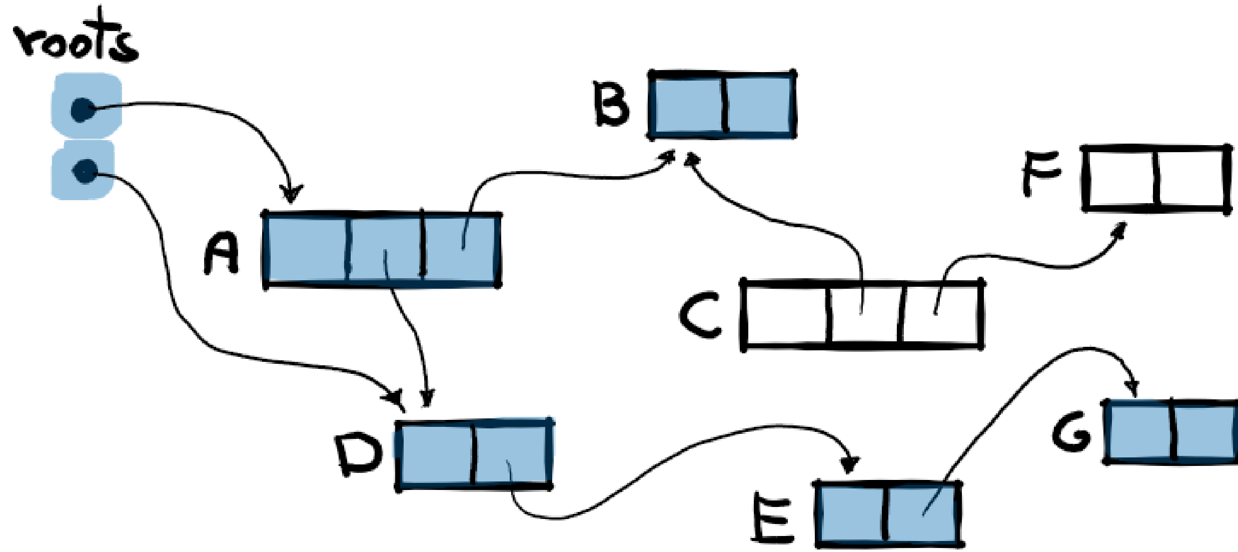

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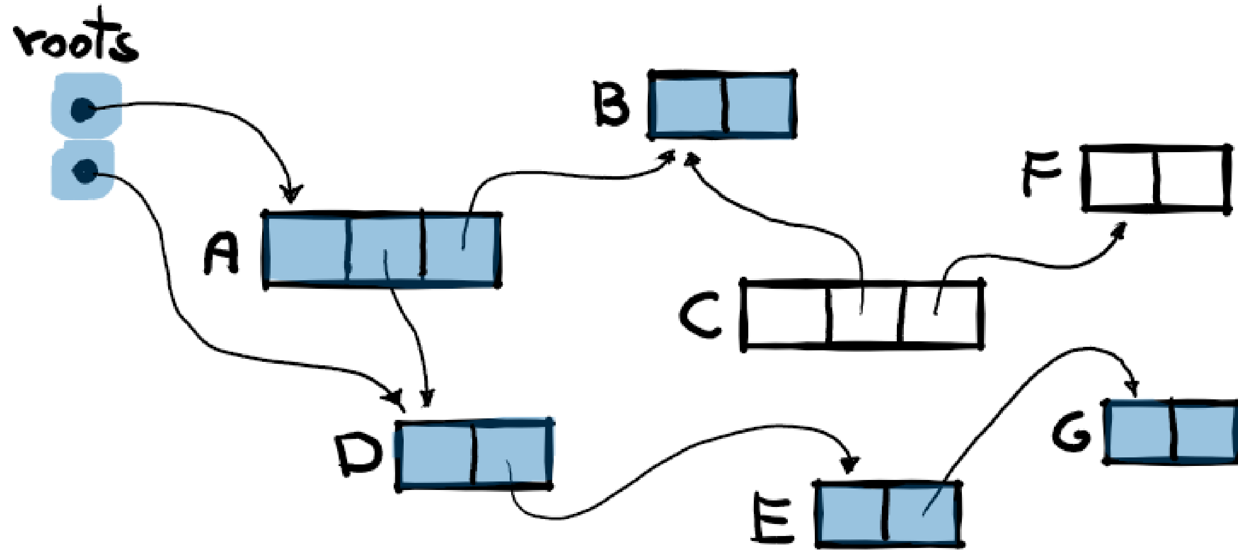

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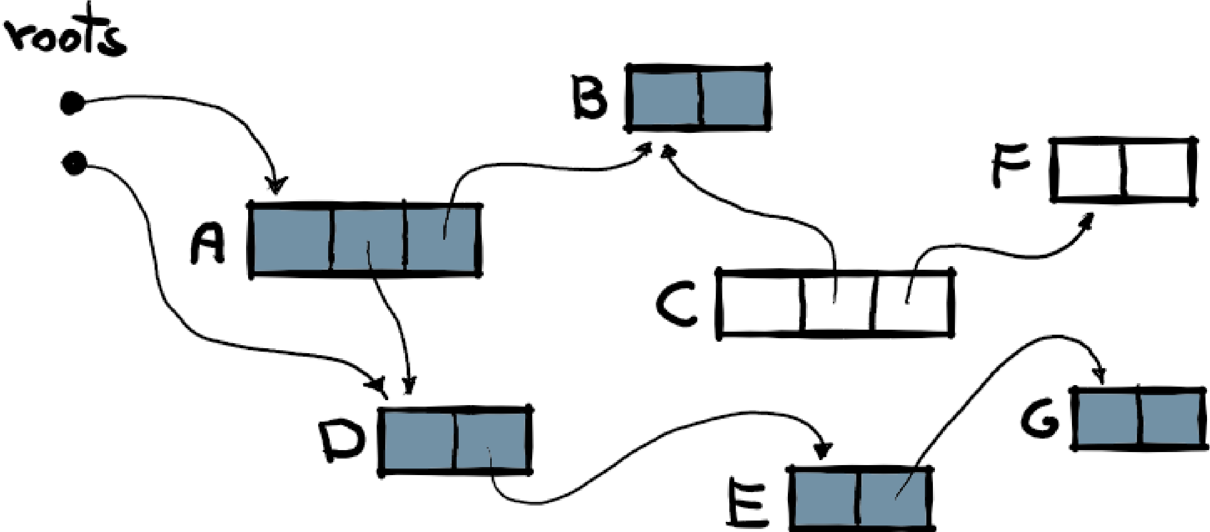

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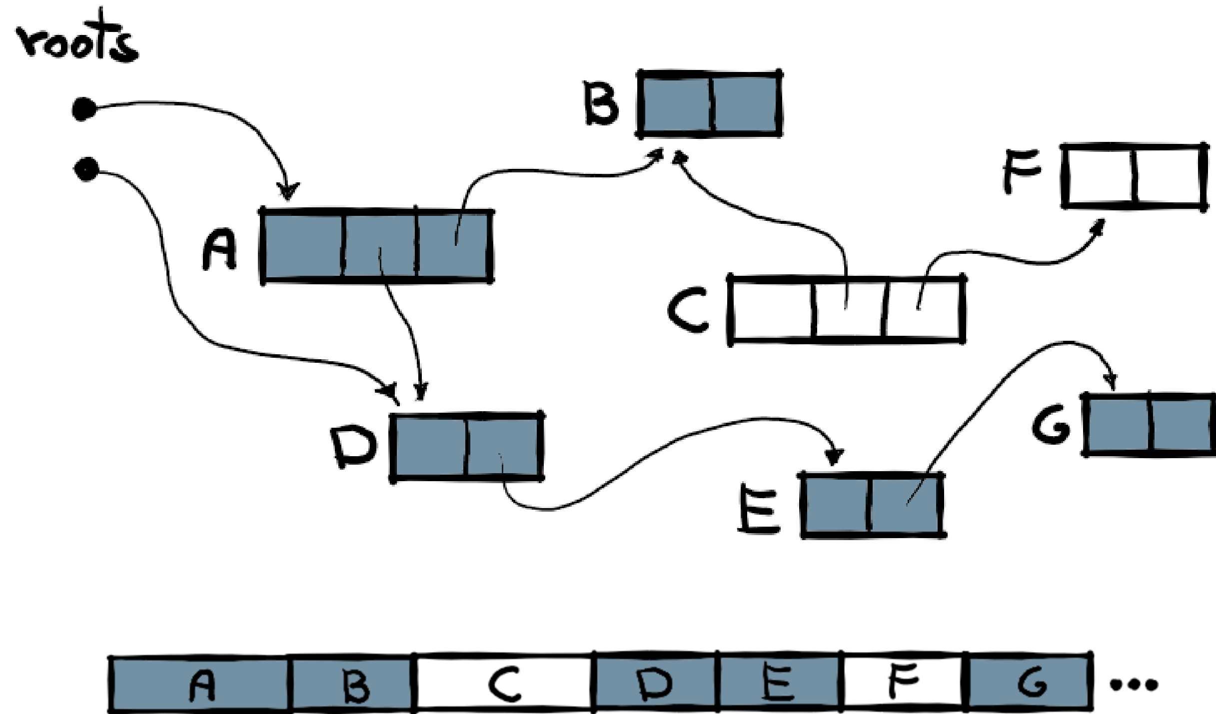

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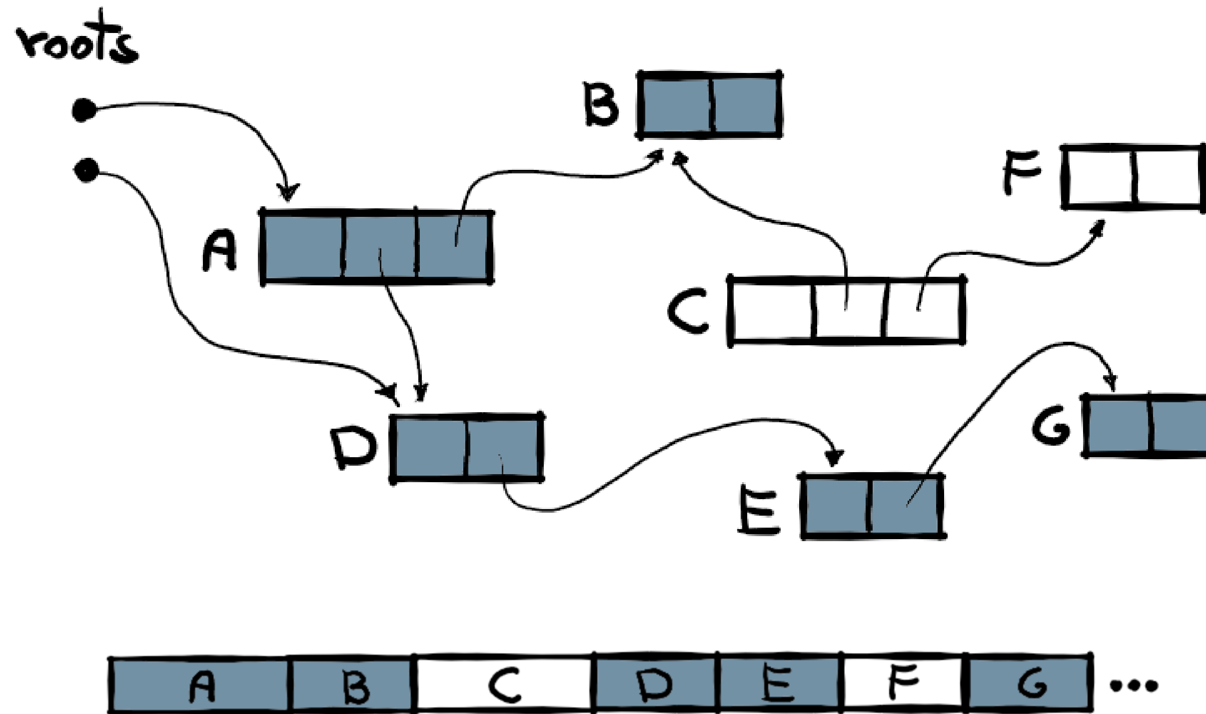
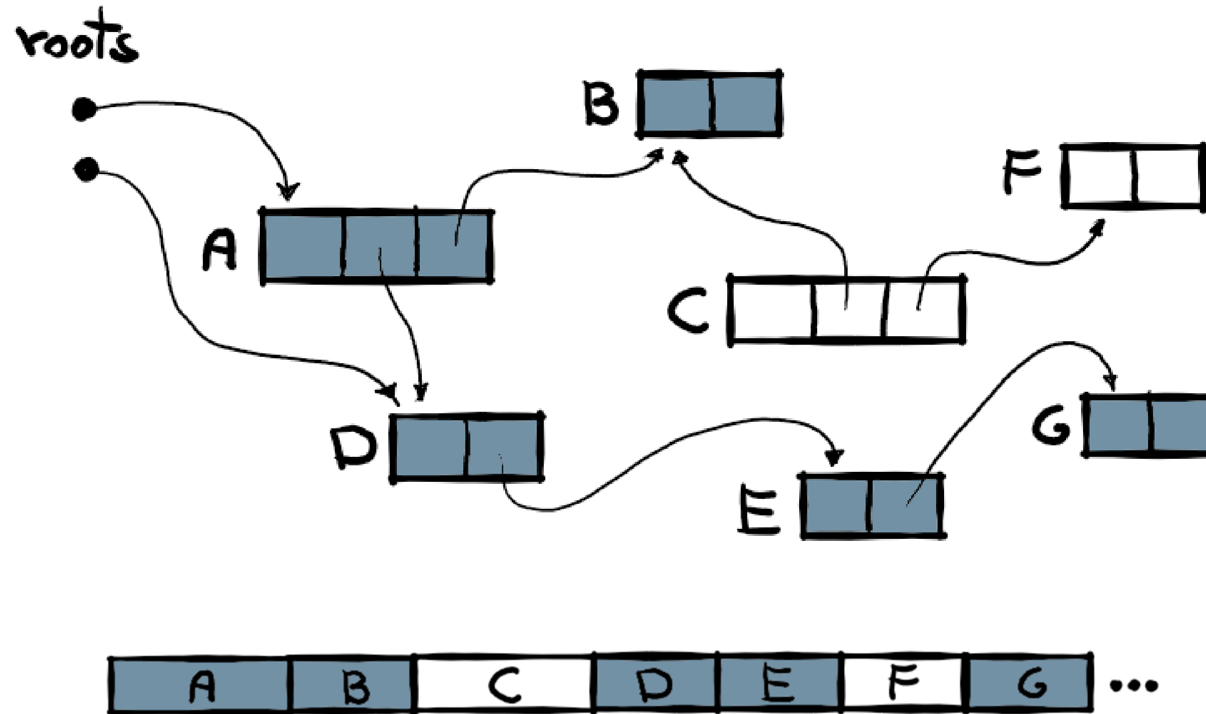


We have just discovered **reachability** of the objects (from at least one root) by *marking algorithm*.

Object graph traversal



We have just discovered **reachability** of the objects (from at least one root) by *marking algorithm*.

Reachability is the closest we can get to true "usability" - we don't know the future.

Object graph traversal - roots

- stack
- registers
- static/thread-local static data
- finalization queue
- inter-generational references ("cards", "card tables") - *we will return to that...*
- ...

Mark phase implementation

Sequentially for every root type (like stack, finalization, ...):

1. Collect the roots into the "to visit list" (**the mark stack**)
2. For each given target address `addr` from the mark stack:
   - set **pinning flag** (in the `Header`) - if the runtime says so
   - start traversal:
     - skip already visited object
     - **mark** an object (in the `MT`)
     - add outgoing references to the **mark stack**

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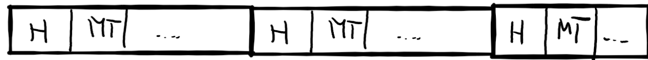
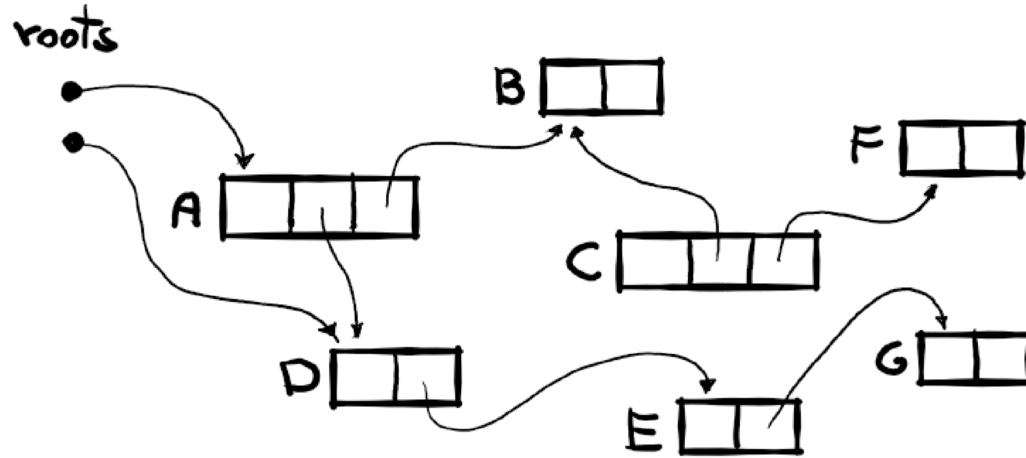
    - start traversal:
        - skip already visited object
        - **mark** an object (in the `MT`)
        - add its address to **the mark list** (if not overflowed)
        - add outgoing references to the **mark stack**

Mark phase - let's draw!





Mark stack:

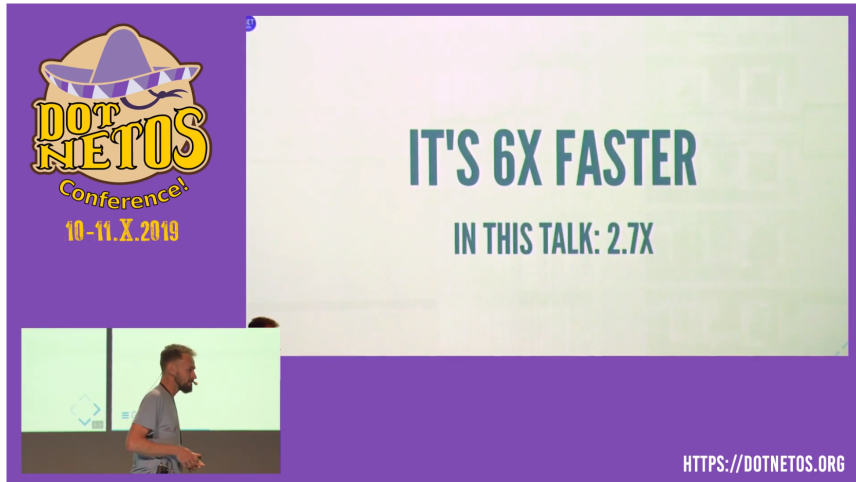
Mark list:

Mark phase

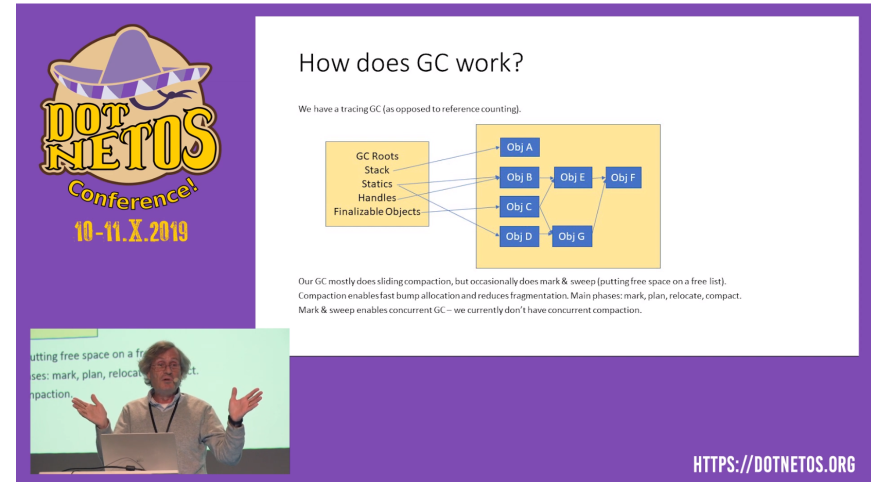
Findings:

- *mark* and *pinned* flags are **added only during the GC** - and **cleared afterwards** at *Plan* phase
  - ie. by looking at a regular memory dump in-between GCs, we won't see those bits set
  - diagnostics tool needs to traverse the graph from roots to notice an object is *pinned*
- mark stack is used as safier approach that recursion
- mark list will help us later, **if sorted**
- it is pretty a lot of work to do (and non-sequential memory access...)!

Mark phase - "mark list sorting story"



Dan Schechter - .NET Intrinsics in CoreCLR 3.0



Peter Sollich - The .NET Garbage Collector

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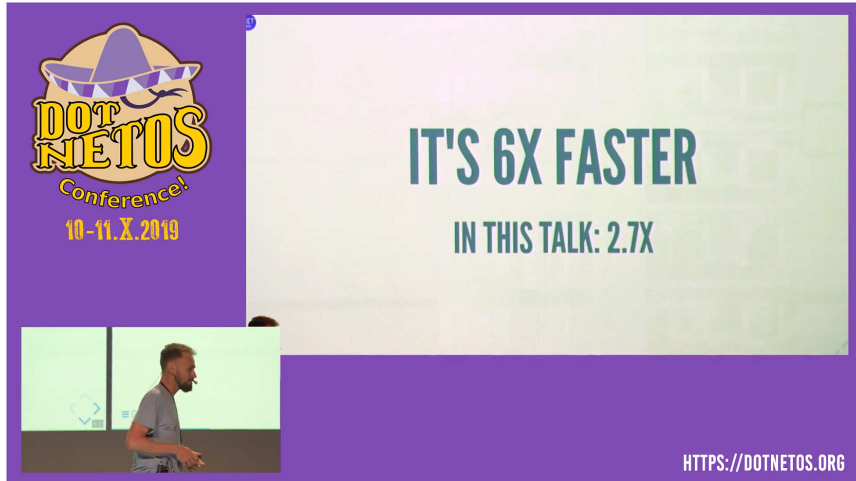

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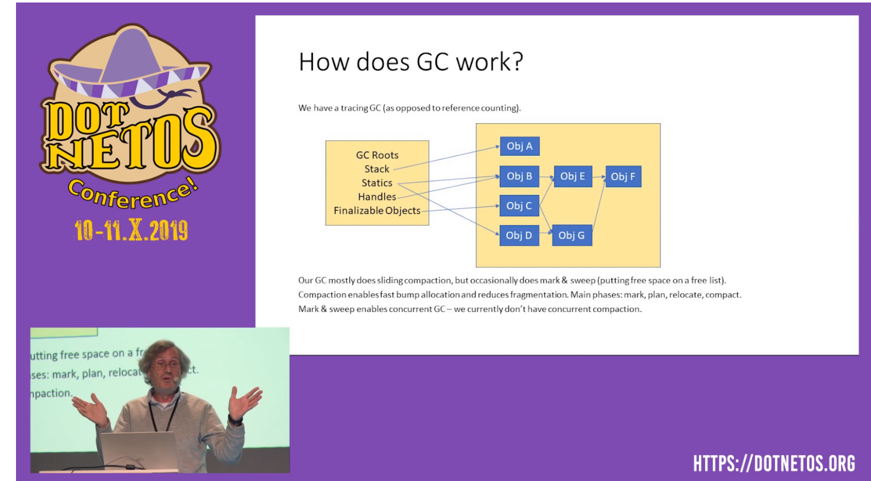

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- Oct 2019 - *"Dan, we could improve our mark list sorting with that..."* - Peter

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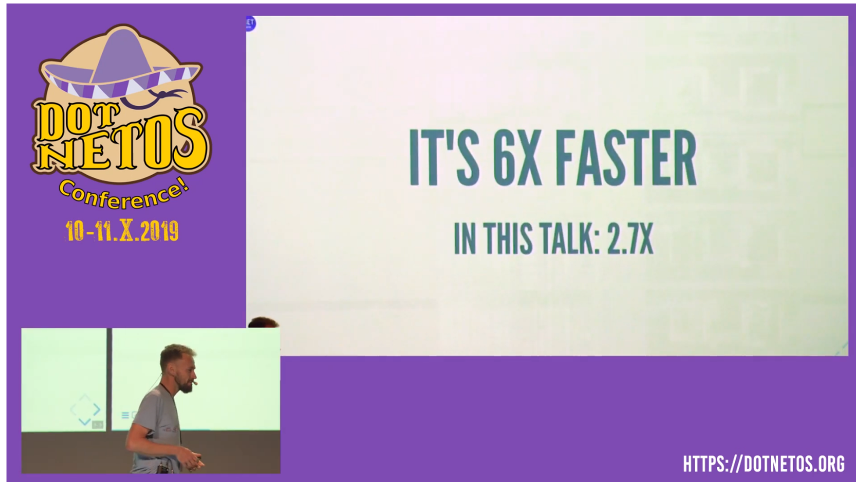

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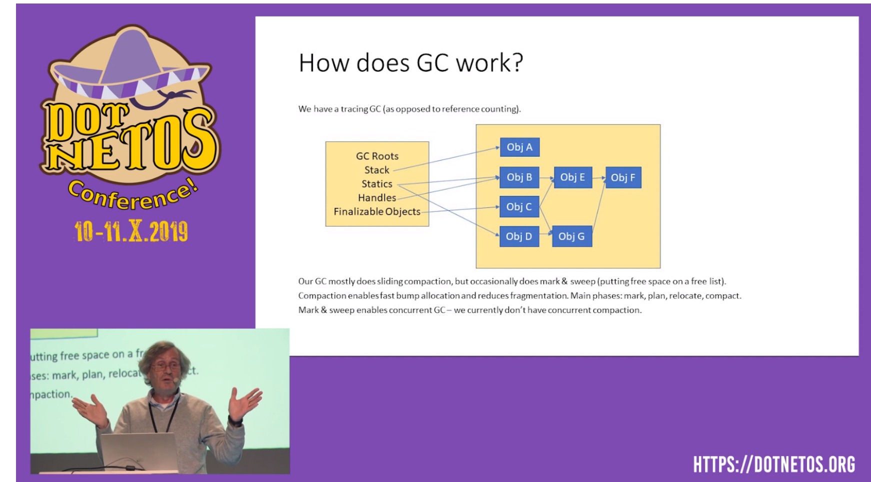

[Peter Sollich - The .NET Garbage Collector]

- Oct 2019 - *"Dan, we could improve our mark list sorting with that..."* - Peter
- Jul 2020 - [https://github.com/dotnet/runtime/pull/37159] - "Vxsort"
  - **faster sorting** code from Dan Shechter, and **bigger mark list**, used for Marking, using AVX2/AVX512F
  - 👉 shorter GC pauses 😍

Mark phase - sidenote #1

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"translate it to the proper address of a managed object" - aka interior pointers

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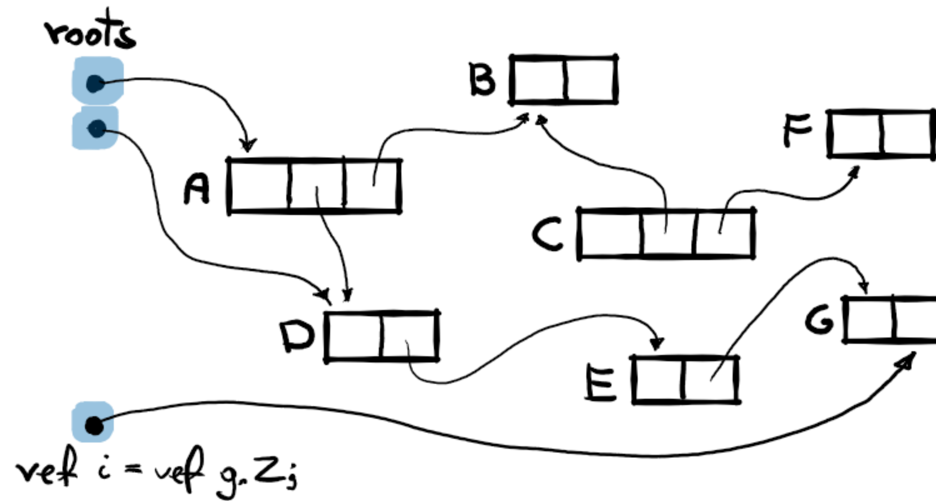
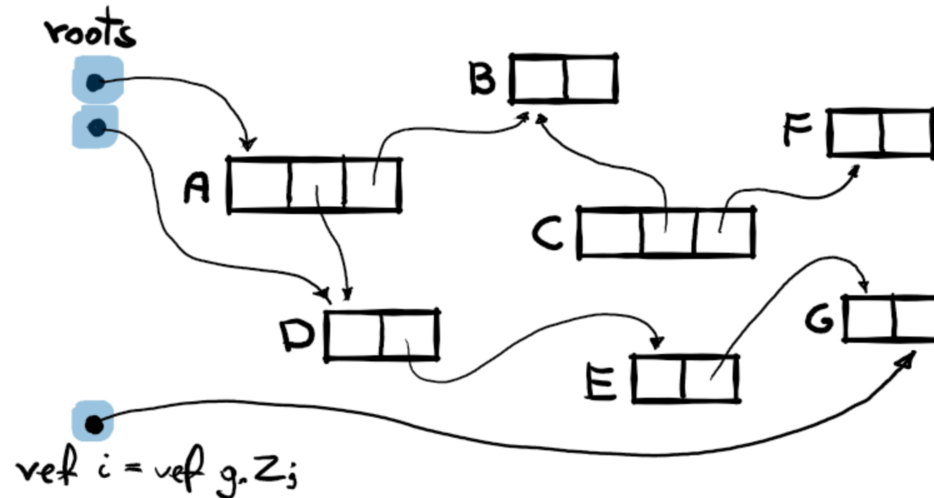


Mark phase - sidenote #1

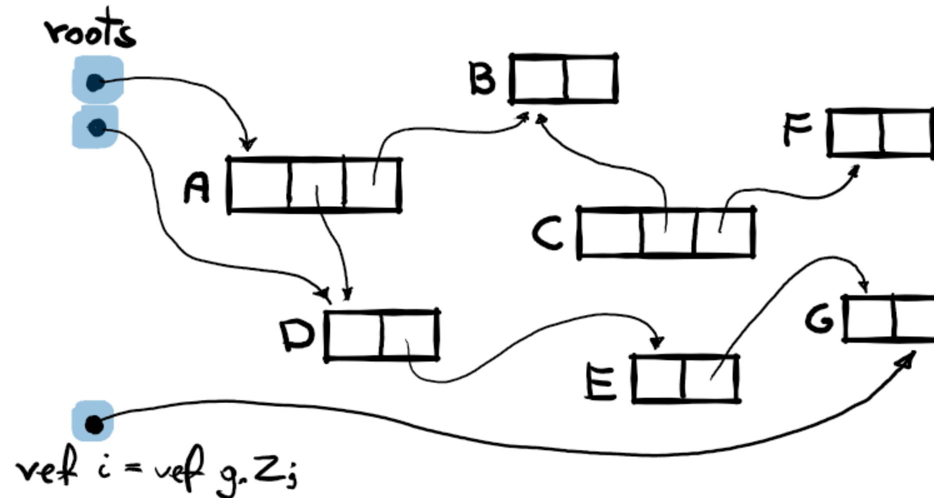
"translate it to the proper address of a managed object" - aka interior pointers




```
void GCHeap::Promote(Object** ppObject, ..., uint32_t flags)
{
    // ...
    if (flags & GC_CALL_INTERIOR)
    {
        if ((o = hp->find_object (o)) == 0)
        {
            return;
        }
```

Mark phase - sidenote #1

"translate it to the proper address of a managed object" - aka interior pointers

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{
    // ...
    if (flags & GC_CALL_INTERIOR)
    {
        if ((o = hp->find_object (o)) == 0) // based on bricks - although not yet available at Mark phase
        {
            return;
        }
```

Mark phase - sidenote #2

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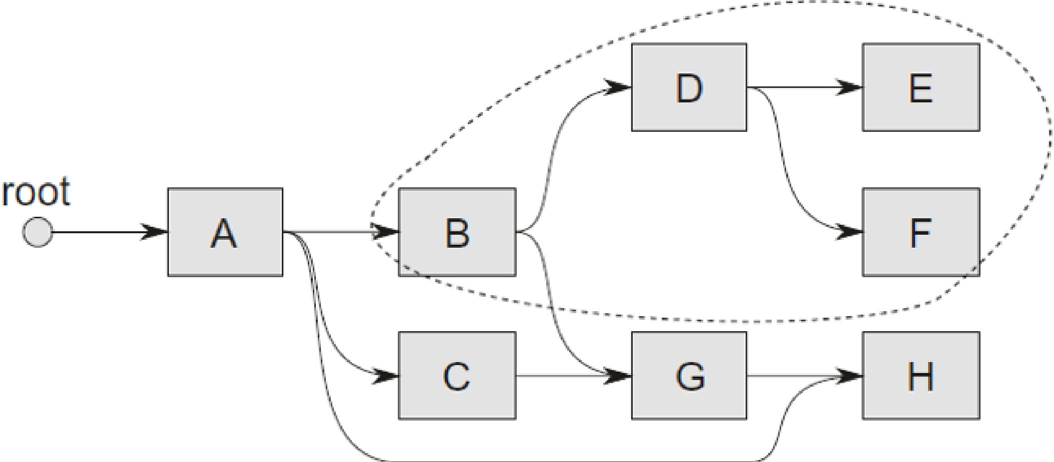
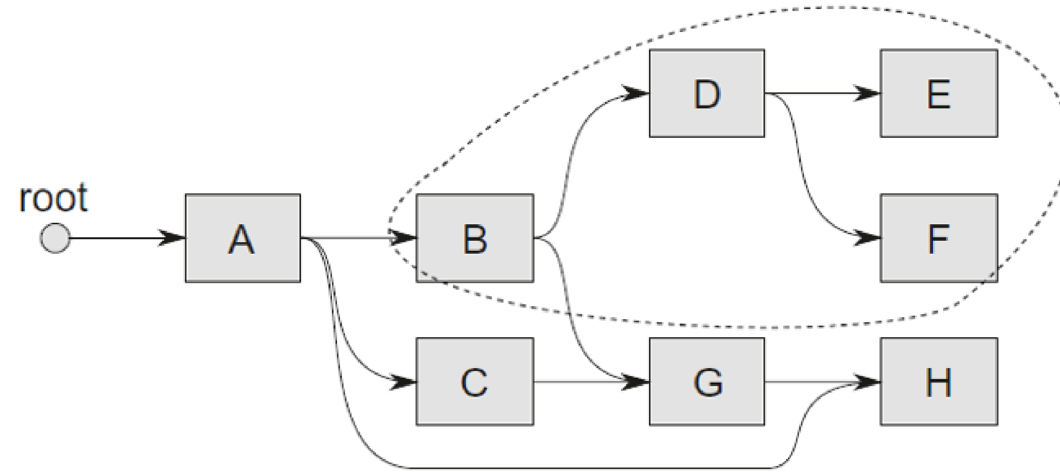


Mark phase - sidenote #2



- shortest root path
- dependency subgraph – total size
- retained subgraph – retained size

Mark phase - inside code

Mark phase starts in the `gc_heap::mark_phase` and has calls to:

- `GCScan::GcScanRoots` that calls `Thread::StackWalkFrames` with `GCHeap::Promote`
- `CFinalize::GcScanRoots` using `GCHeap::Promote`
- `GCScan::GcScanHandles` (with `GCHeap::Promote` callback) methods that calls `Ref_TracePinningRoots` (for types `HNDTYPE_PINNED` and `HNDTYPE_ASYNCPINNED`), `Ref_TraceNormalRoots` (fe. for type `HNDTYPE_STRONG`) etc.
- `gc_heap::mark_through_cards_for_segments` (for SOH) and `gc_heap::mark_through_cards_for_large_objects` (for LOH)
- `GCScan::GcDhInitialScan` and `scan_dependent_handles` handle scanning "dependent handles"

`GCHeap::Promote` method calls the `go_through_object_cl` macro that triggers traversal through objects' references. The main work is done in `gc_heap::mark_object_simple1` that realizes depth-first object graph traversal using "mark stack" called `mark_stack_array` (with `mark_stack_bos` and `mark_stack_tos` indexes pointing to the bottom and the top of the stack). Setting "mark bit" happens in `gc_mark(o)`/`gc_mark1(o)` methods.

Mark phase - inside code

Additionally, **`gc_heap::mark_object_simple`**/**`gc_heap::mark_object_simple1`** methods, while traversal, are using **`m_boundary`** macro to populare **`mark_list`**.

Mark list is maintained/sorted only for "non concurrent" ephemeral GC (*"multiple segments are more complex to handle and the list is likely to overflow"*). Sorting happens in:

- **`mark_phase`** (only iff **`PARALLEL_MARK_LIST_SORT`** & **`MULTIPLE_HEAPS`**) calling **`gc_heap::sort_mark_list`** (using **`do_vxsort`** if **`USE_VXSORT`**)
- **`plan_phase`** (only iff **`!MULTIPLE_HEAPS`**) using **`do_vxsort`** (if **`USE_VXSORT`**)

If mark list overflows, we expand it up to maximum in **`gc_heap::grow_mark_list`**:

```
// with vectorized sorting, we can use bigger mark lists
#ifdef USE_VXSORT
#ifdef MULTIPLE_HEAPS
    const size_t MAX_MARK_LIST_SIZE = IsSupportedInstructionSet (InstructionSet::AVX2) ? 1000 * 1024 : 200 * 102
#else //MULTIPLE_HEAPS
    const size_t MAX_MARK_LIST_SIZE = IsSupportedInstructionSet (InstructionSet::AVX2) ? 32 * 1024 : 16 * 1024;
#endif //MULTIPLE_HEAPS
#else
...
```

Thank you! Any questions?!