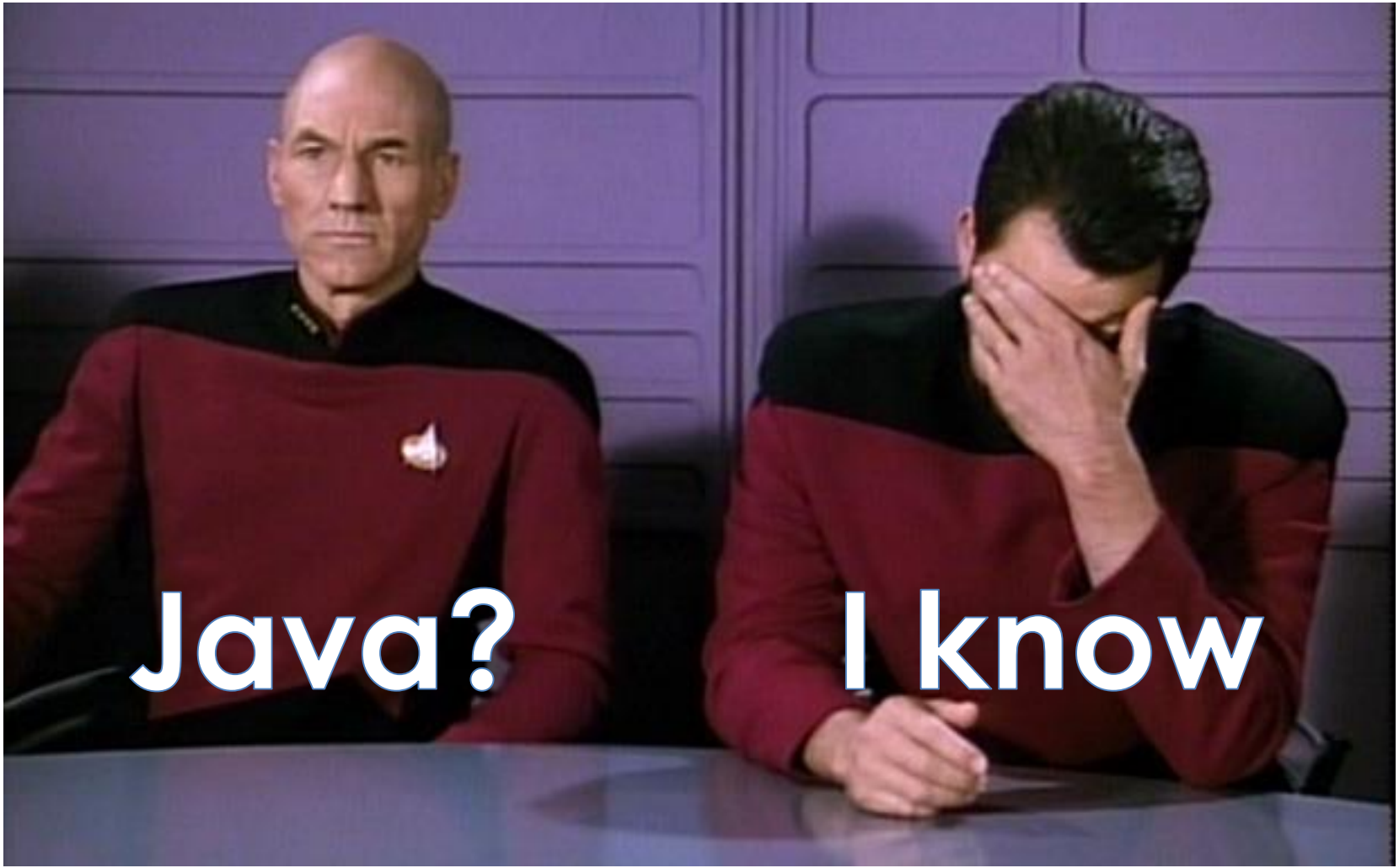
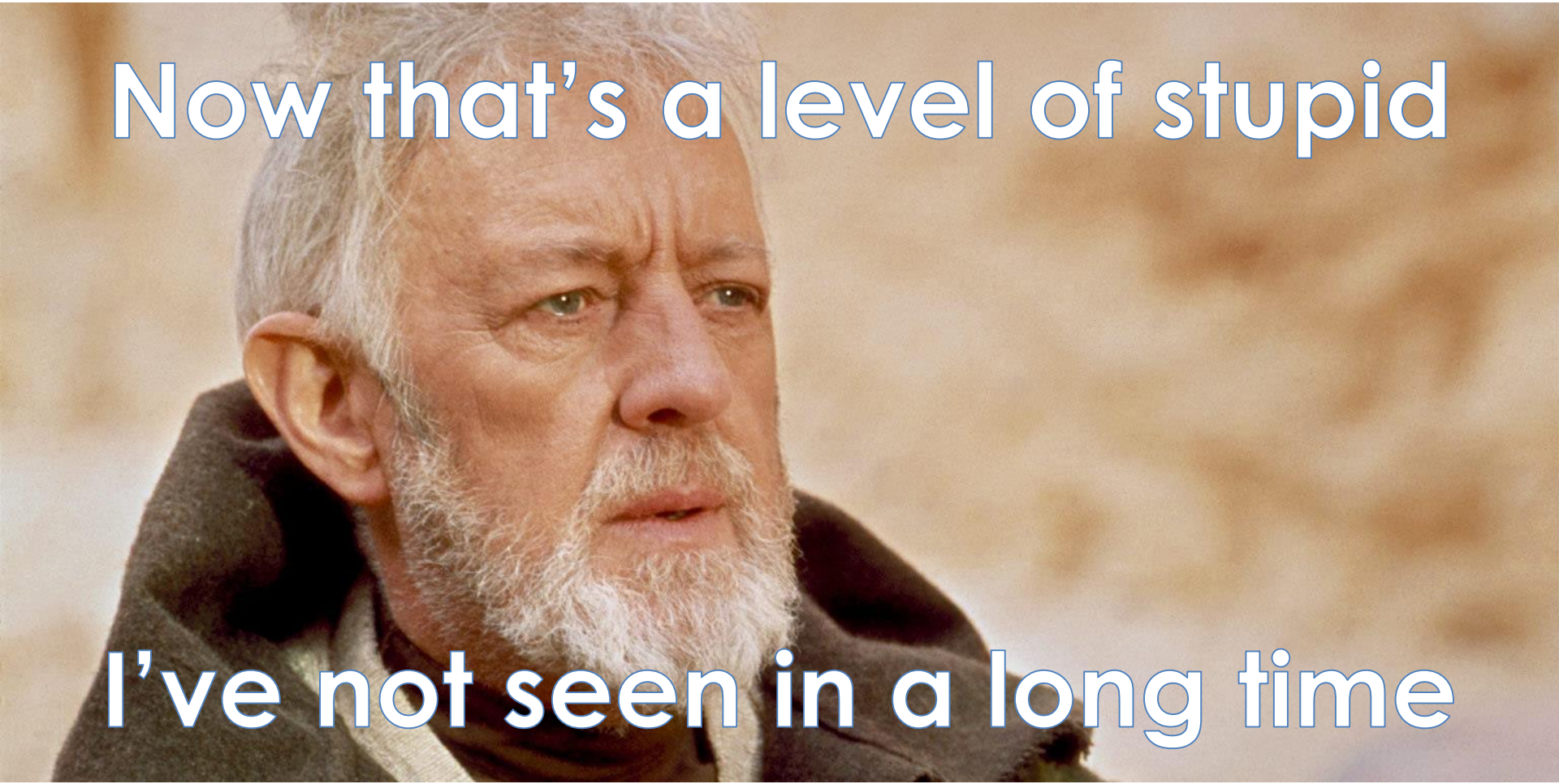
High Performance Managed Languages

Martin Thompson - @mjpt777

Really, what is your preferred platform for building HFT applications?


Java?
I know

Why do you build low-latency applications on a GC'ed platform?


Now that's a level of stupid
I've not seen in a long time

Agenda

1. Let’s set some Context
2. Runtime Optimisation
3. Garbage Collection
4. Algorithms & Design

Some Context

Let’s be clear

A Managed Runtime is not always the best choice…

Latency Arbitrage?


Altera®
FPGA

Two questions…

Why build on a Managed Runtime?

Can managed languages provide good performance?

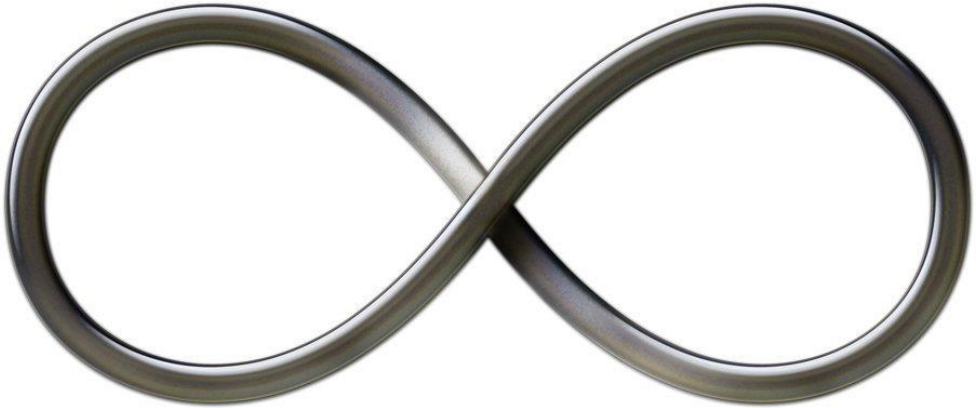
We need to follow the evidence…

“You investigate for curiosity, because it is unknown, not because you know the answer.”

Richard Feynman

Are native languages faster?

Time?



Skills & Resources?

What can, or should, be outsourced?

CPU vs Memory Performance

How much time to perform an addition operation on 2 integers?

1 CPU Cycle
< 1ns

Sequential Access

-

Average time in ns/op to sum all longs in a 1GB array?

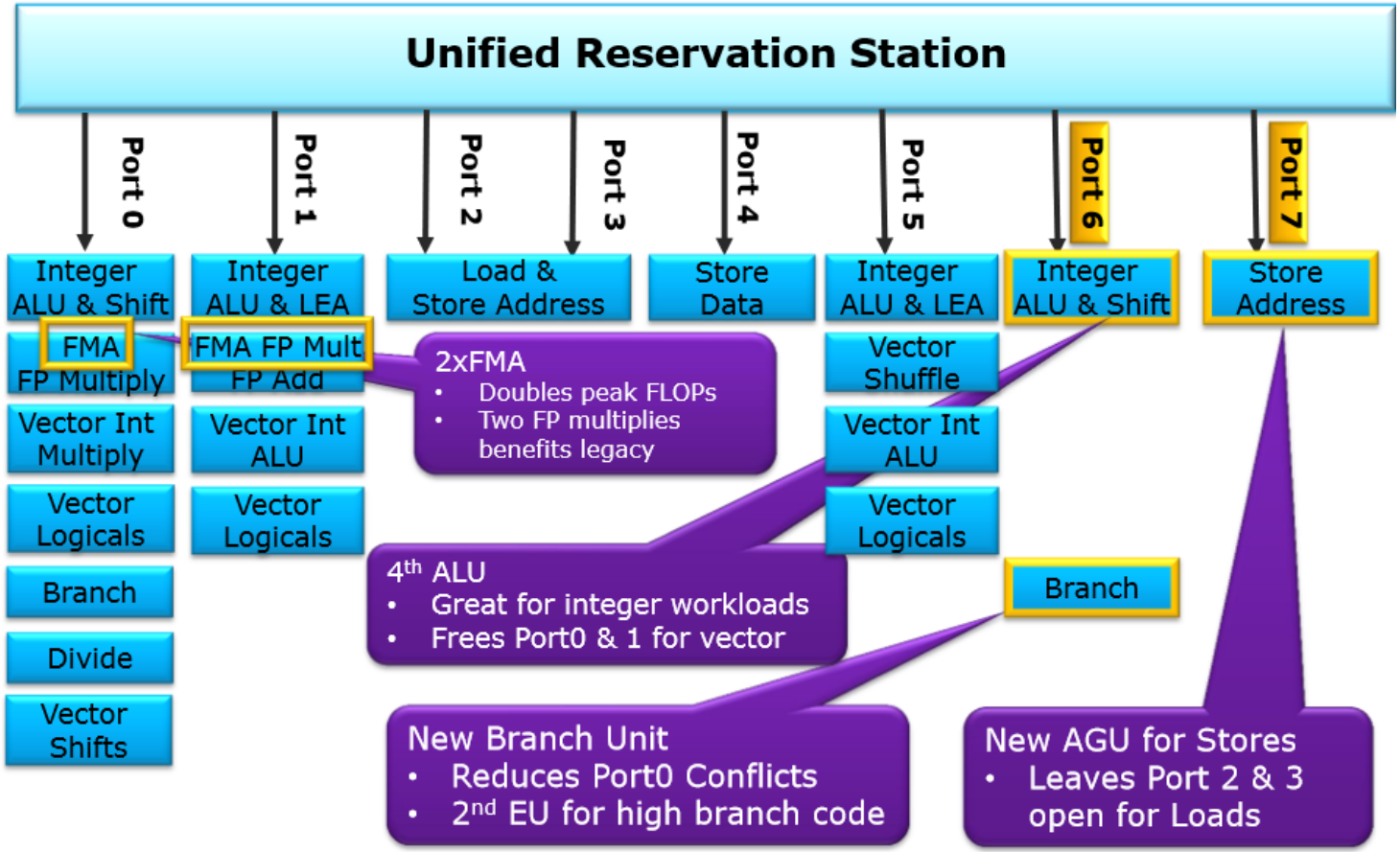
Access Pattern Benchmark

Benchmark	Mode	Score	Error	Units
testSequential	avgt	0.832	± 0.006	ns/op

~1 ns/op

Really???
Less than 1ns per operation?

Haswell Execution Unit Overview



Random walk per OS Page

-

Average time in ns/op to sum all longs in a 1GB array?

Access Pattern Benchmark

```
Benchmark                      Mode    Score     Error  Units

testSequential                 avgt    0.832   ± 0.006  ns/op
testRandomPage                 avgt    2.703   ± 0.025  ns/op
```

~3 ns/op

Data dependant walk per OS Page

-

Average time in ns/op to sum all longs in a 1GB array?

Access Pattern Benchmark

Benchmark	Mode	Score	Error	Units
testSequential	avgt	0.832	± 0.006	ns/op
testRandomPage	avgt	2.703	± 0.025	ns/op
testDependentRandomPage	avgt	7.102	± 0.326	ns/op

~7 ns/op

Random heap walk

-

Average time in ns/op to sum all longs in a 1GB array?

Access Pattern Benchmark

Benchmark	Mode	Score	Error	Units
testSequential	avgt	0.832	± 0.006	ns/op
testRandomPage	avgt	2.703	± 0.025	ns/op
testDependentRandomPage	avgt	7.102	± 0.326	ns/op
testRandomHeap	avgt	19.896	± 3.110	ns/op

~20 ns/op

Data dependant heap walk

-

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Benchmark	Mode	Score	Error	Units
testSequential	avgt	0.832	± 0.006	ns/op
testRandomPage	avgt	2.703	± 0.025	ns/op
testDependentRandomPage	avgt	7.102	± 0.326	ns/op
testRandomHeap	avgt	19.896	± 3.110	ns/op
testDependentRandomHeap	avgt	89.516	± 4.573	ns/op

~90 ns/op

Then ADD 40+ ns/op
for NUMA access on a server!!!!

Data Dependent Loads aka “Pointer Chasing”!!!

Performance 101

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1. Memory is transported in Cachelines

Performance 101

1. Memory is transported in Cachelines
2. Memory is managed in OS Pages

Performance 101

1. Memory is transported in Cachelines
2. Memory is managed in OS Pages
3. Memory is pre-fetched on predictable access patterns

Runtime Optimisation

Runtime JIT

1. Profile guided optimisations

Runtime JIT

1. Profile guided optimisations

2. Bets can be taken and later revoked

Branches

```
void foo()
{
    // code

    if (condition)
    {
        // code

    }

    // code
}
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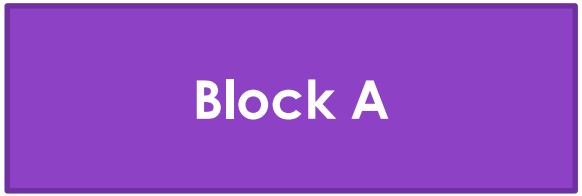

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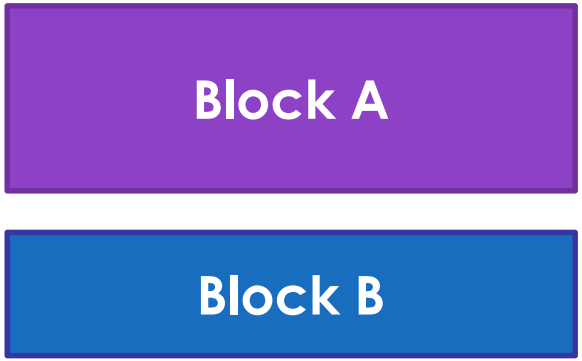

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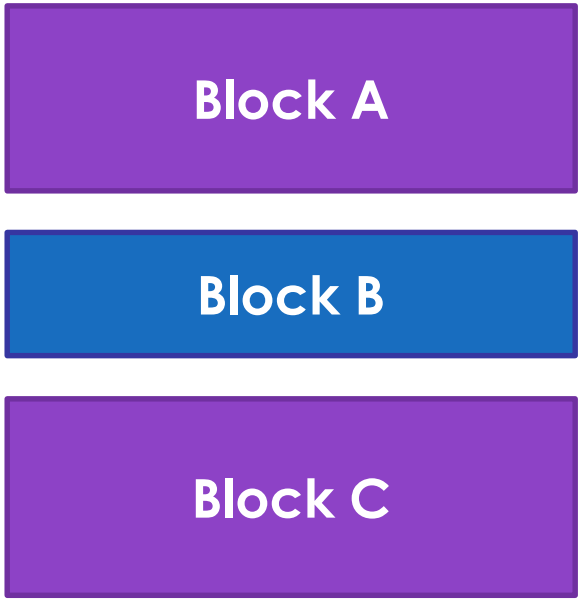

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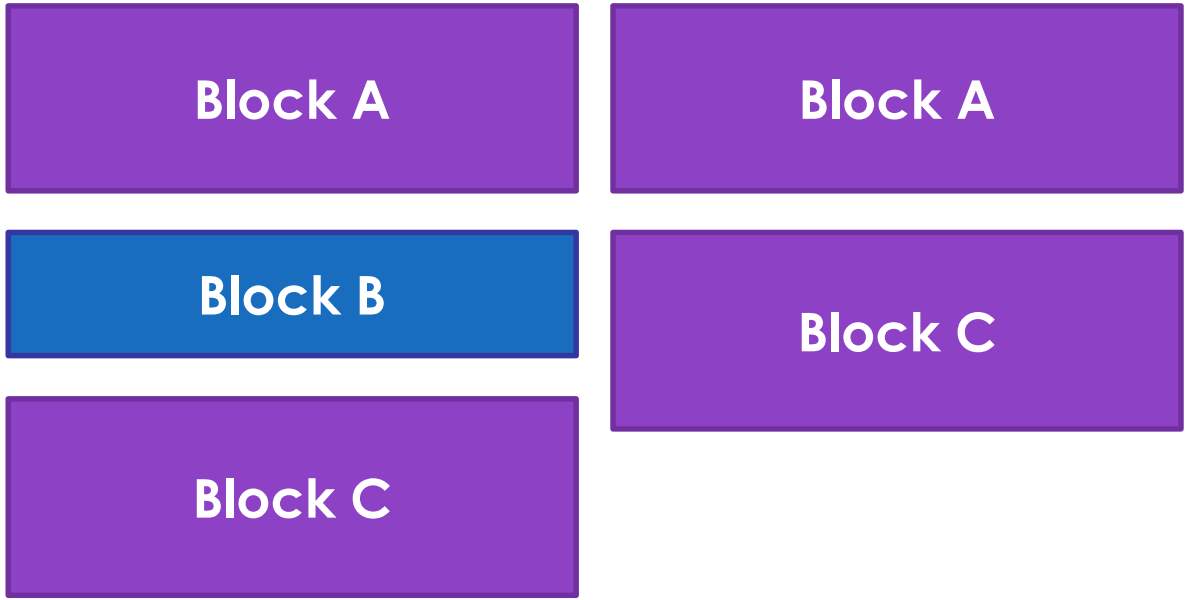

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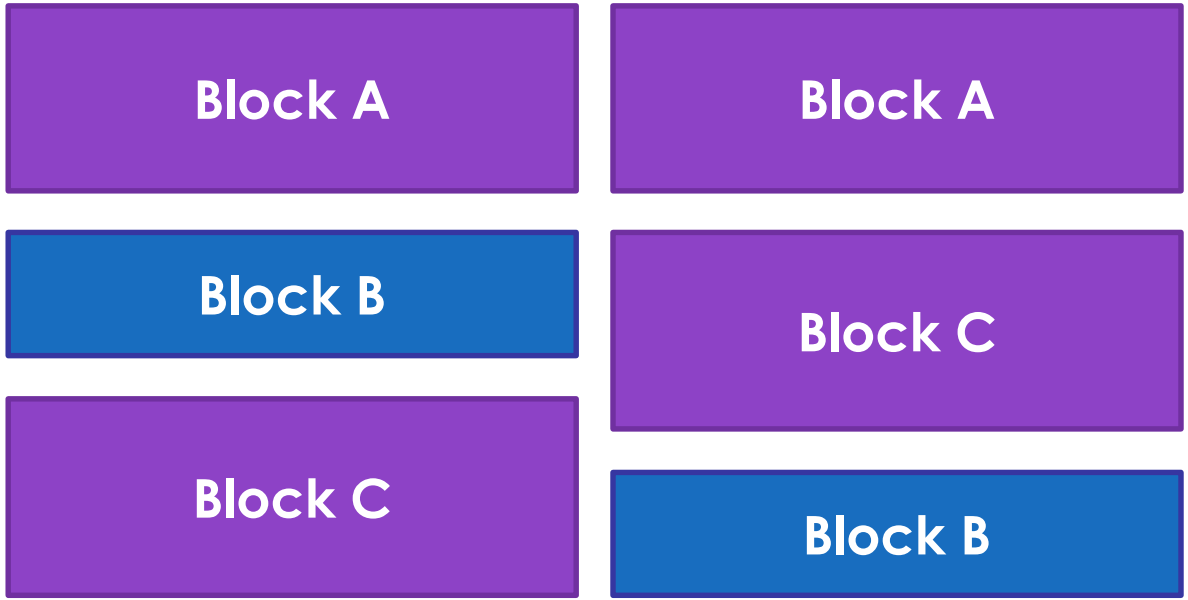

Subtle Branches

```
int result = (i > 7) ? a : b;
```

Subtle Branches

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int result = (i > 7) ? a : b;
```

CMOV vs Branch Prediction?

Method/Function Inlining

```
void foo()
{
    // code

    bar();

    // code
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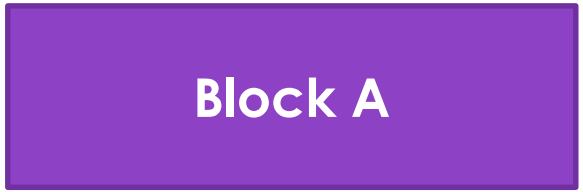

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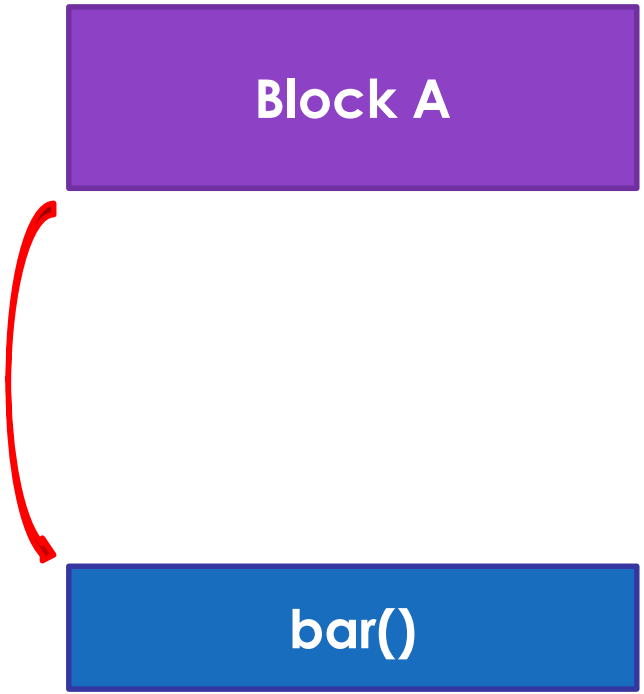

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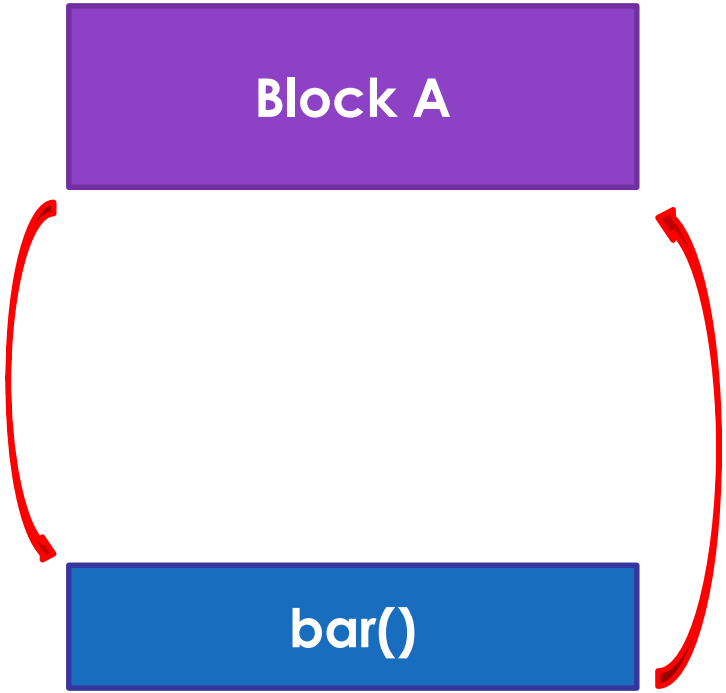

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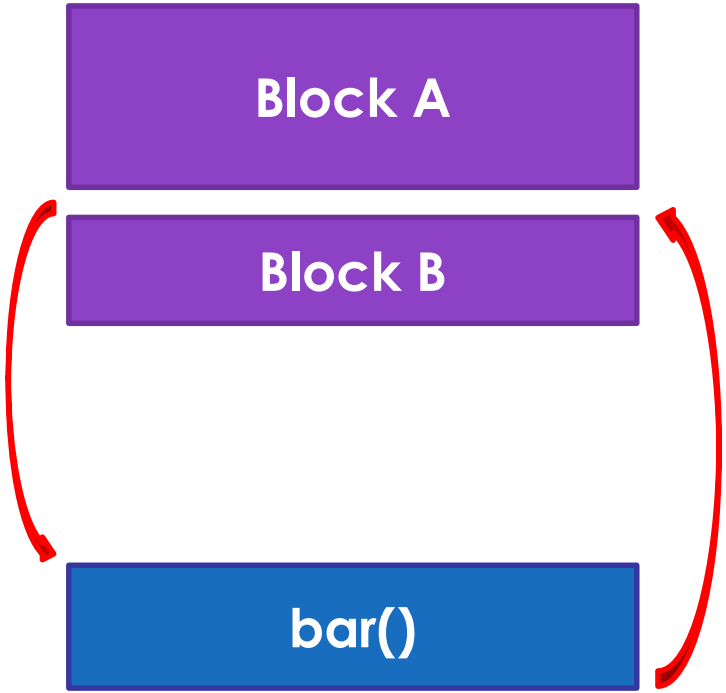

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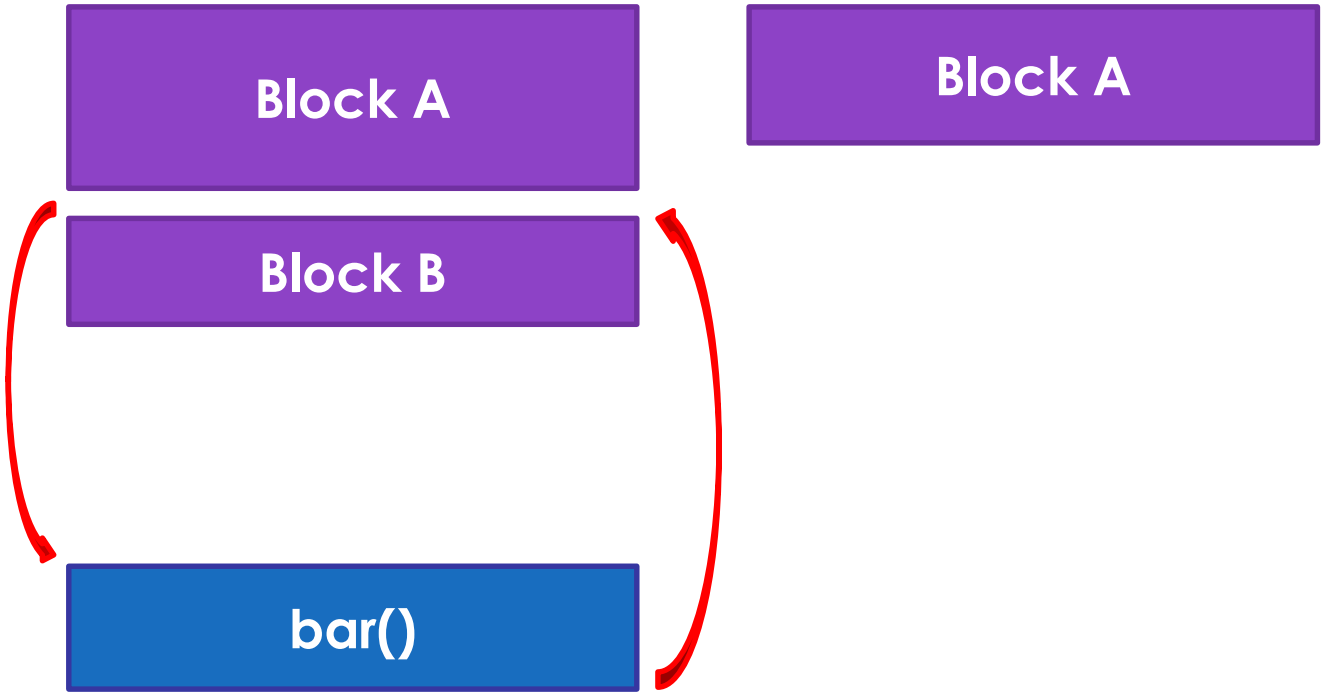

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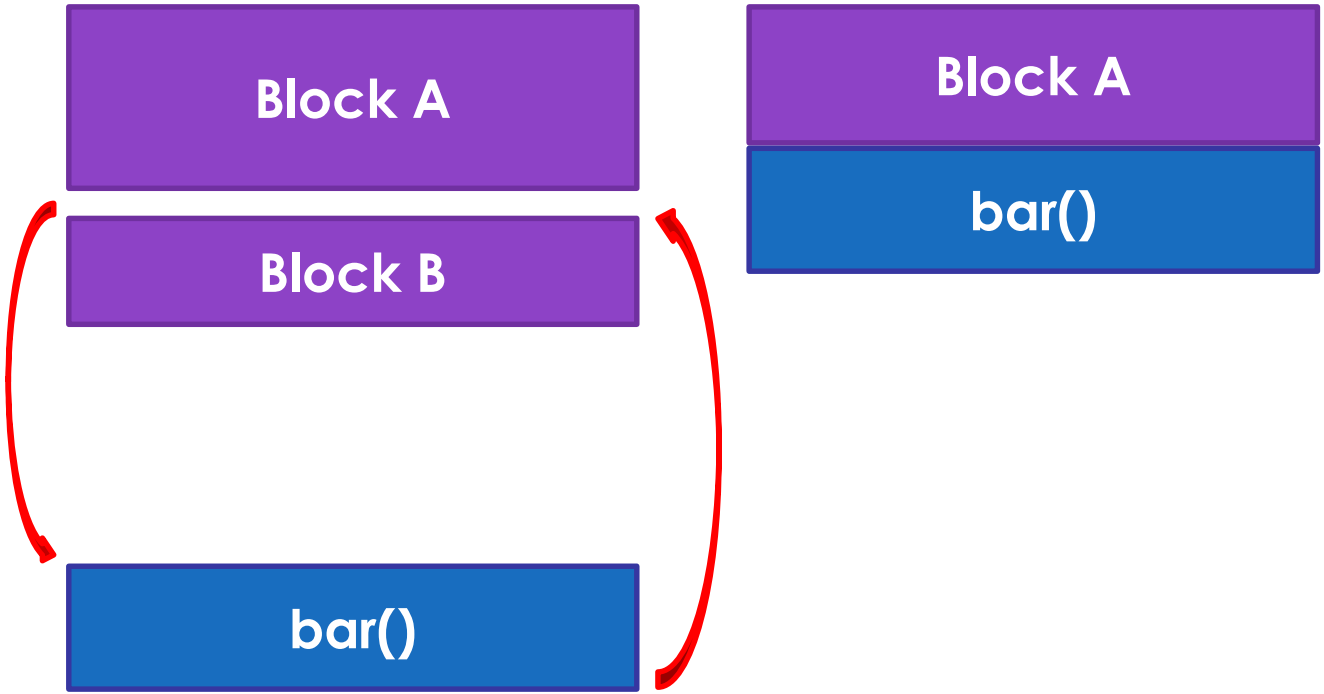

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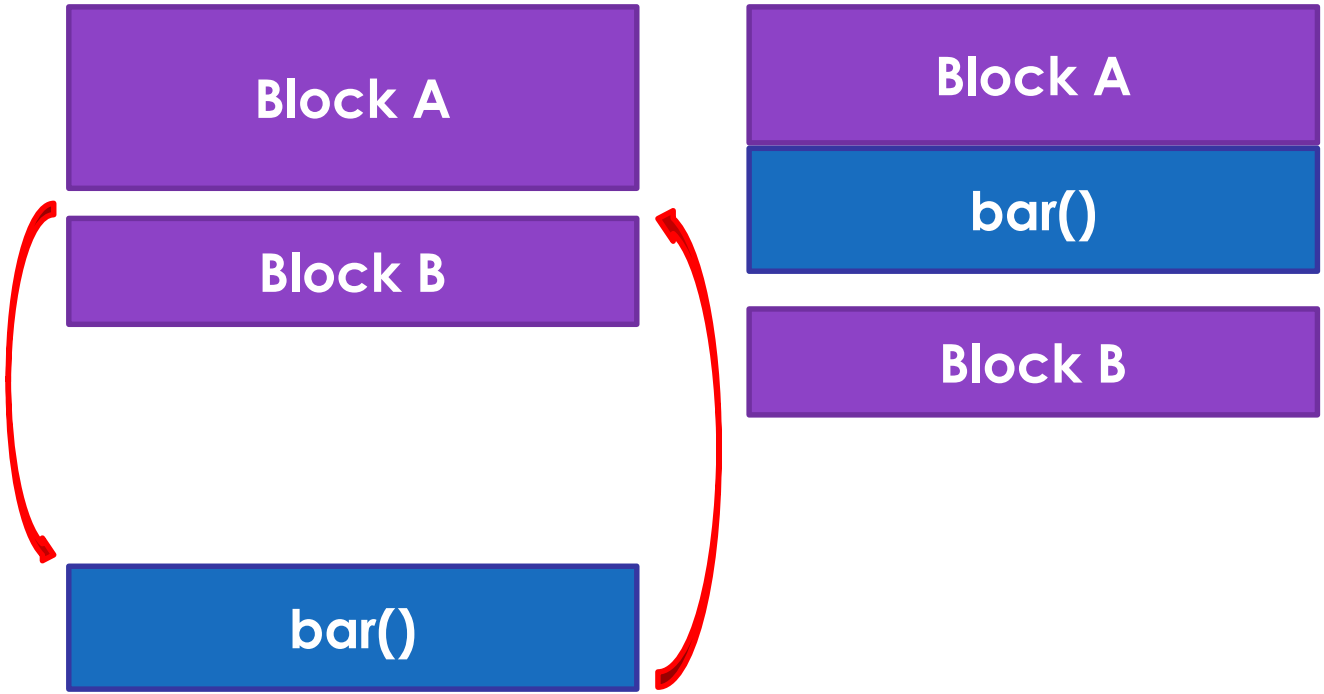

Method/Function Inlining

```
void foo()
{
    // code

    bar();

    // code
}
```

i-cache
& code bloat?

Method/Function Inlining

"Inlining is THE optimisation."

- Cliff Click

Bounds Checking

```
void foo(int[] array, int length)
{
    // code

    for (int i = 0; i < length; i++)
    {
        bar(array[i]);
    }

    // code
}
```

Bounds Checking

```
void foo(int[] array)
{
    // code

    for (int i = 0; i < array.length; i++)
    {
        bar(array[i]);
    }

    // code
}
```

Subtype Polymorphism

```
void draw(Shape[] shapes)
{
    for (int i = 0; i < shapes.length; i++)
    {
        shapes[i].draw();
    }
}

void bar(Shape shape)
{
    bar(shape.isVisible());
}
```

Subtype Polymorphism

```
void draw(Shape[] shapes)
{
    for (int i = 0; i < shapes.length; i++)
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        shapes[i].draw();
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}

void bar(Shape shape)
{
    bar(shape.isVisible());
}
```

Class Hierarchy Analysis & Inline Caching

Runtime JIT

1. Profile guided optimisations

2. Bets can be taken and later revoked

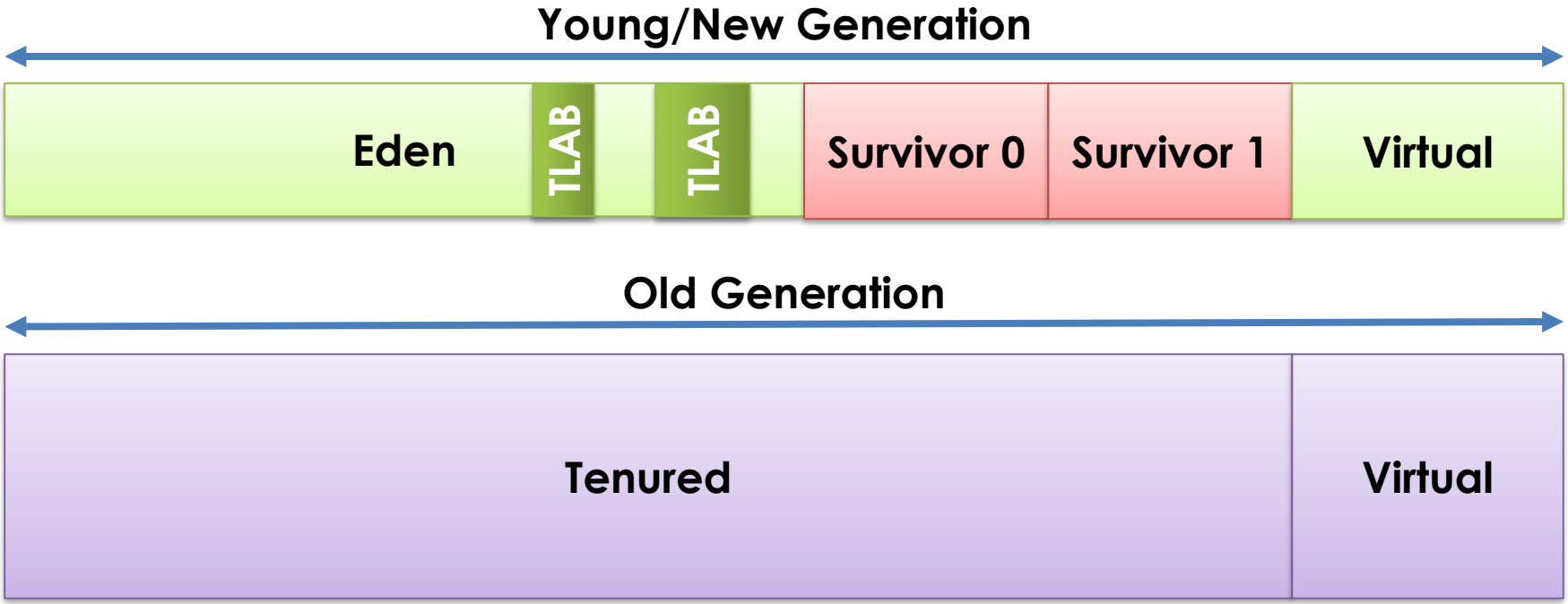
Garbage Collection

Generational Garbage Collection

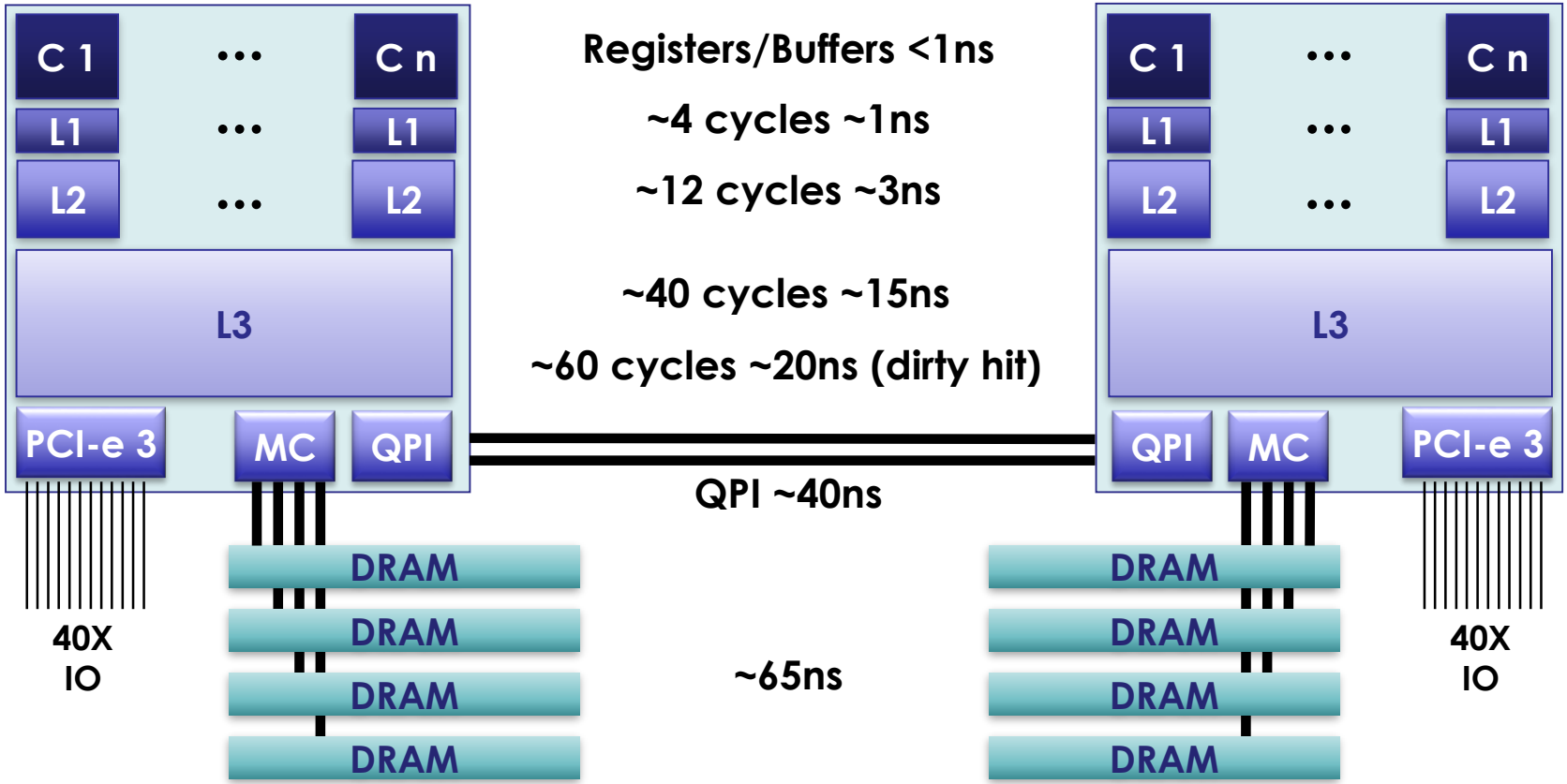
"Only the good die young."

- Billy Joel

Generational Garbage Collection

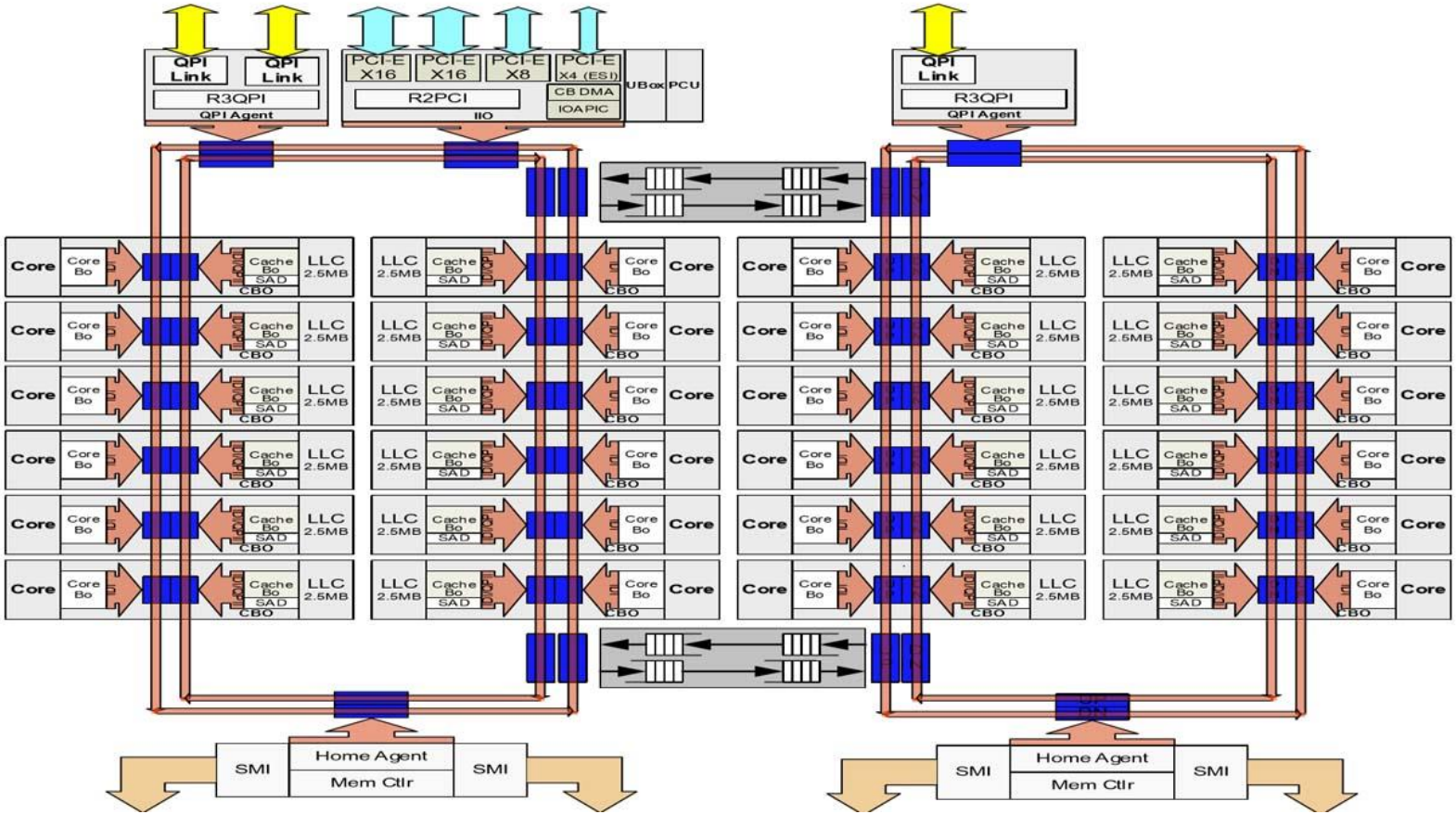


Modern Hardware (Intel Sandy Bridge EP)



* Assumption: 3GHz Processor

Broadwell EX – 24 cores & 60MB L3 Cache

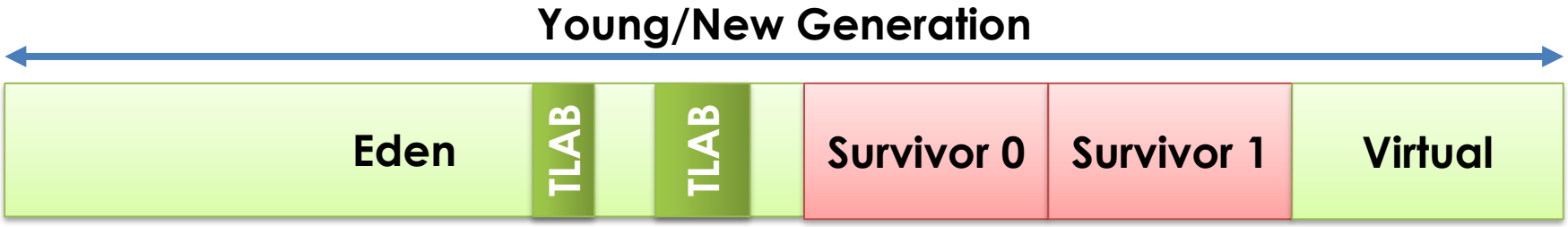


Thread Local Allocation Buffers

Thread Local Allocation Buffers

- Affords locality of reference
- Avoid false sharing
- Can have NUMA aware allocation

Object Survival



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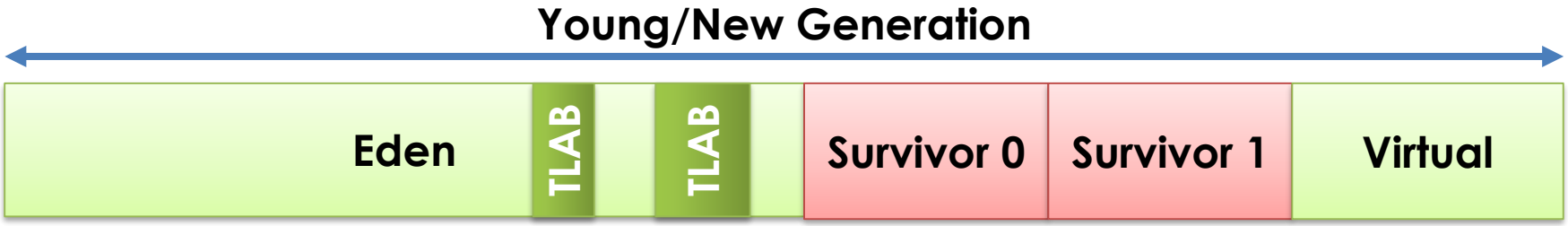
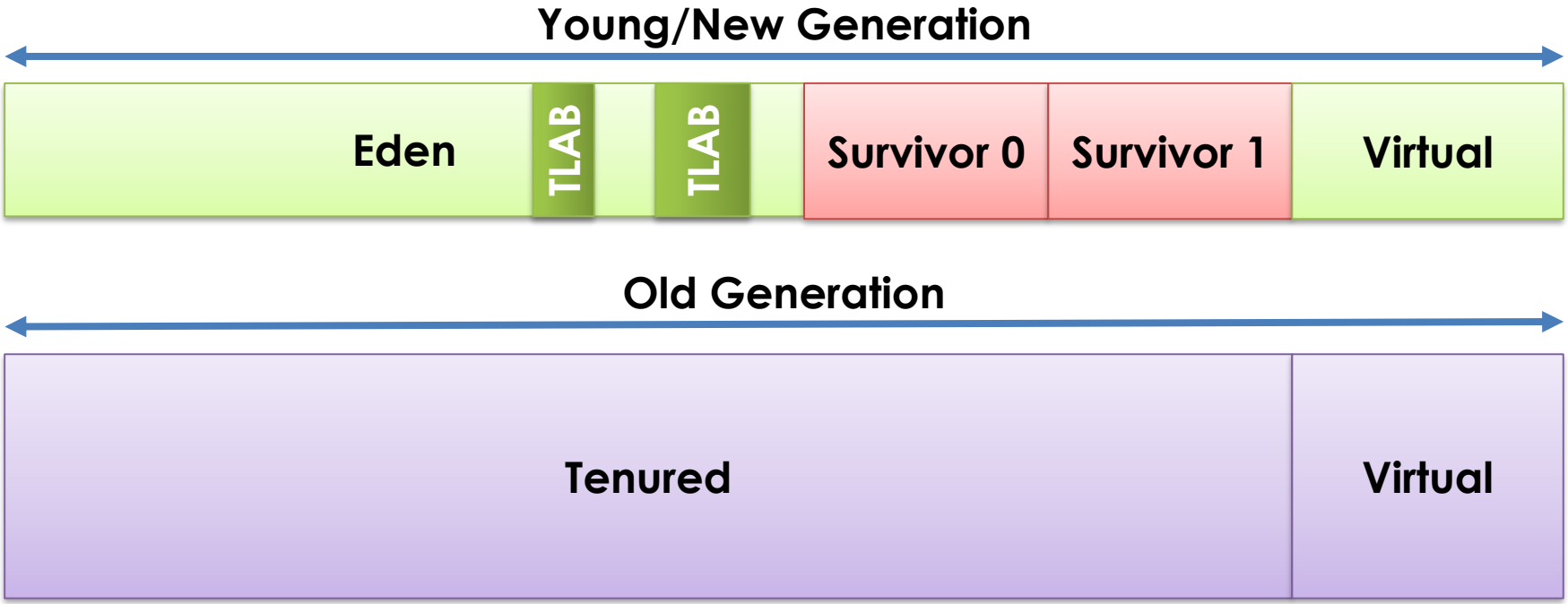
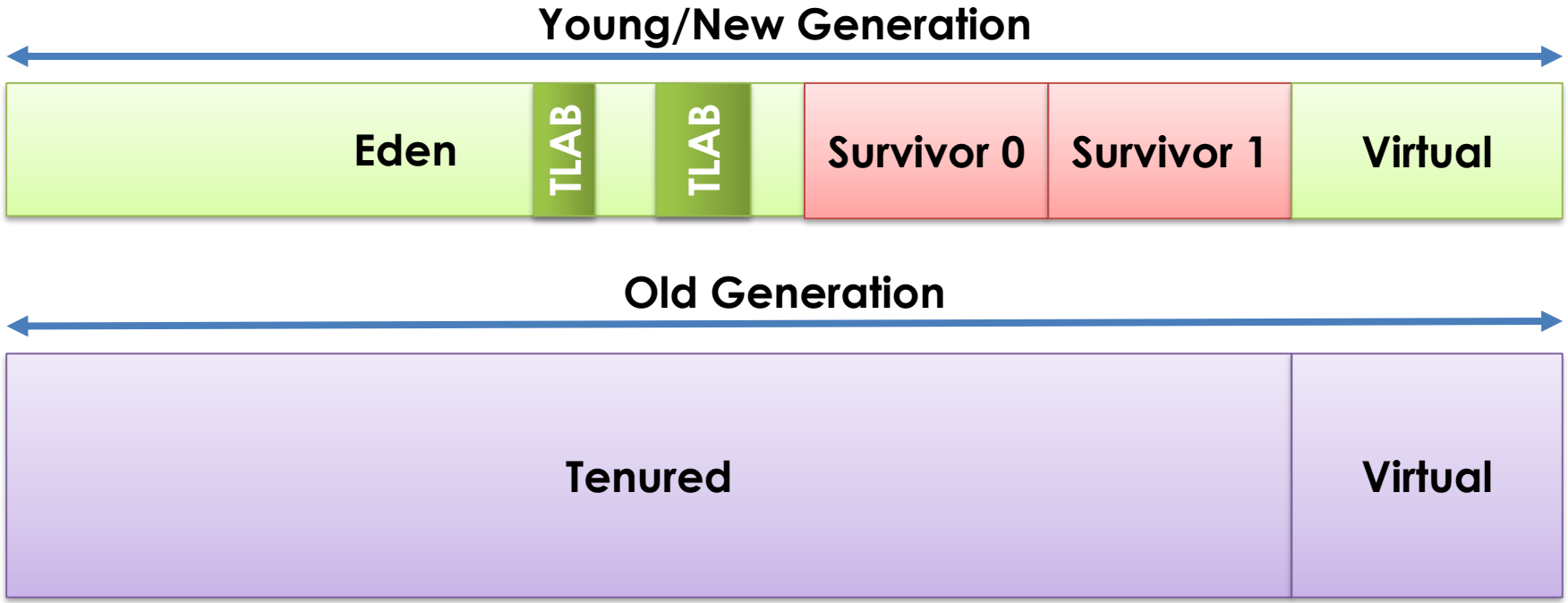


- Aging Policies
- Compacting Copy
- NUMA Interleave
- Fast Parallel Scavenging
- Only the survivors require work

Object Promotion

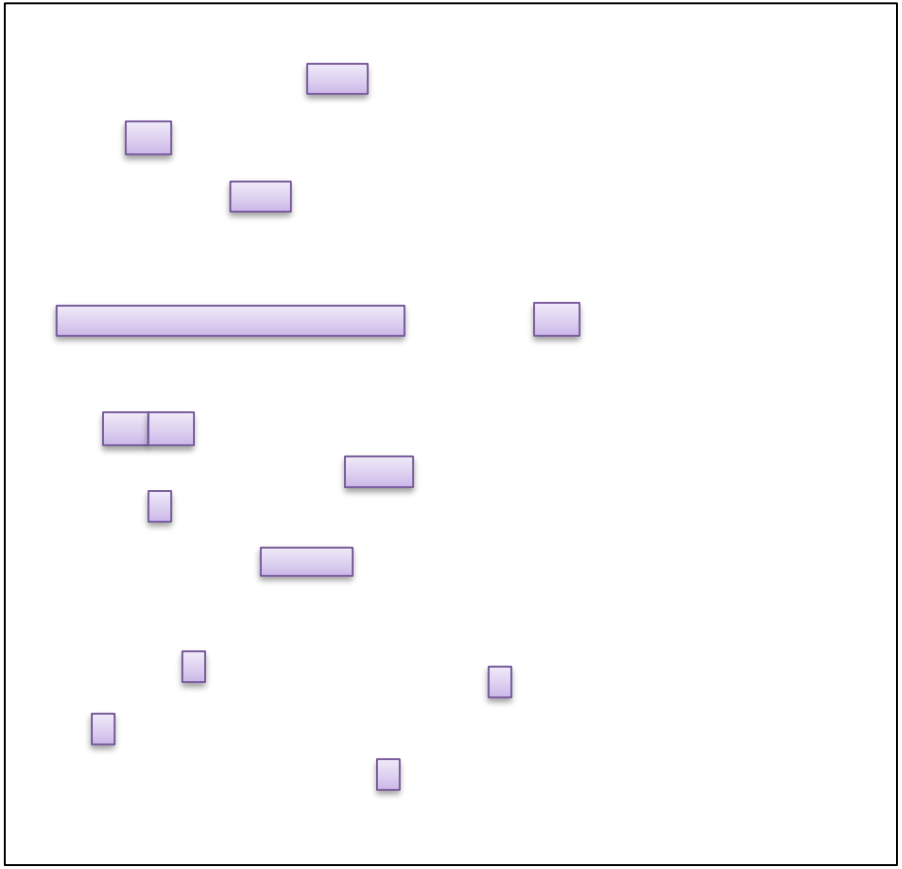


Object Promotion

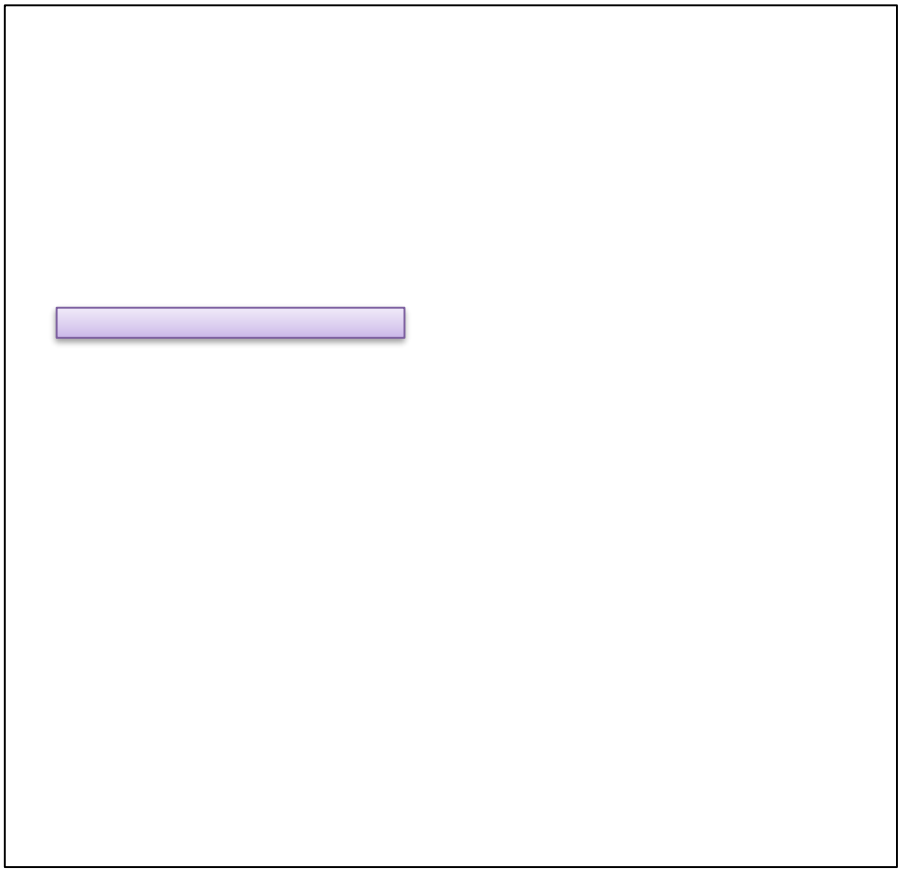


- Concurrent Collection
- String Deduplication

Compacting Collections



Compacting Collections – Depth first copy

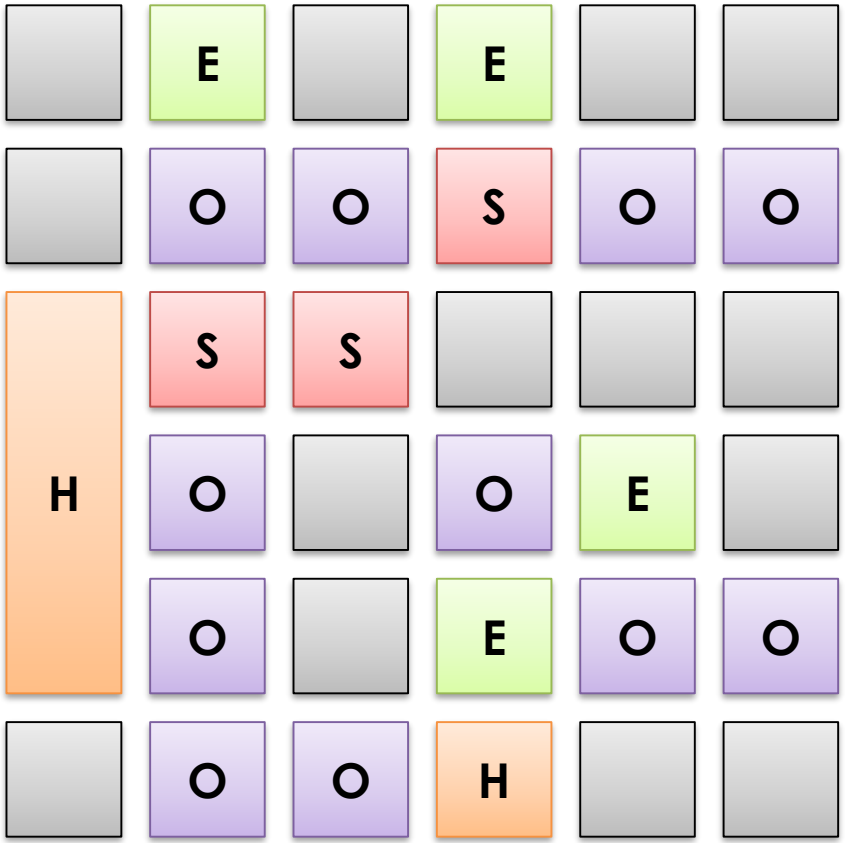


Compacting Collections

Compacting Collections

OS Pages and cache lines?

G1 – Concurrent Compaction



E Eden

S Survivor

O Old

H Humongous

Unused

Azul Zing C4
True Concurrent Compacting Collector

Where next for GC?

Object Inlining/Aggregation

GC vs Manual Memory Management

Not easy to pick clear winner…

GC vs Manual Memory Management

Not easy to pick clear winner…

Managed GC

- GC Implementation
- Card Marking
- Read/Write Barriers
- Object Headers
- Background Overhead in CPU and Memory

GC vs Manual Memory Management

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- GC Implementation
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Native

- Malloc Implementation
- Arena/pool contention
- Bin Wastage
- Fragmentation
- Debugging Effort
- Inter-thread costs

Algorithms & Design

What is most important to performance?

- Avoiding cache misses
- Strength Reduction
- Avoiding duplicate work
- Amortising expensive operations
- Mechanical Sympathy
- Choice of Data Structures
- Choice of Algorithms
- API Design
- Overall Design

In a large codebase it is really difficult to do everything well

It also takes some "*uncommon*" disciplines such as: profiling, telemetry, modelling…

“If I had more time, I would have written a shorter letter.”

- Blaise Pascal

The story of Aeron

Aeron is an interesting lesson in “time to performance”

Lots of others exists such at the C# Roslyn compiler

Time spent on

Mechanical Sympathy
vs
Debugging Pointers

???

Immutable Data & Concurrency

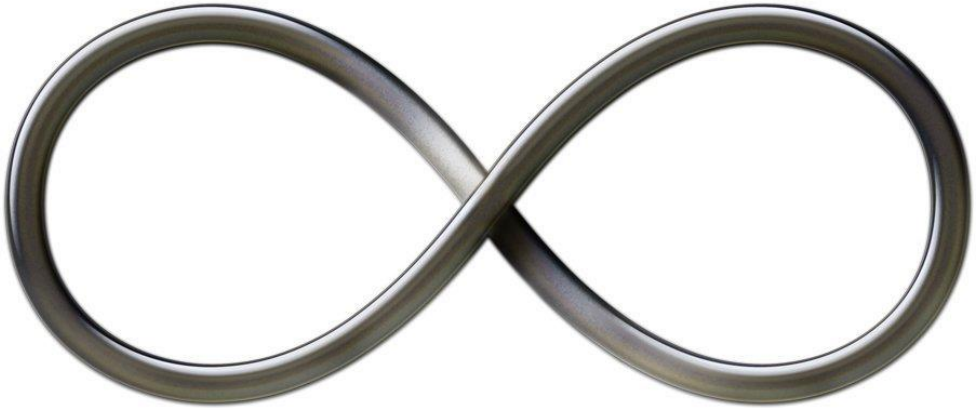
Functional Programming

In Closing …

What does the future hold?

Remember
Assembly vs Compiled Languages

What about the issues of footprint, startup time, GC pauses, etc. ???



Questions?

Blog: http://mechanical-sympathy.blogspot.com/

Twitter: @mjpt777

"Any intelligent fool can make things bigger, more complex, and more violent.

It takes a touch of genius, and a lot of courage, to move in the opposite direction."

- Albert Einstein