Allocation Folding Based on Dominance

Daniel Clifford, Hannes Payer, Michael Starzinger and Ben L. Titzer

International Symposium on Memory Management (ISMM) 2014

presented by Thomas Hütter

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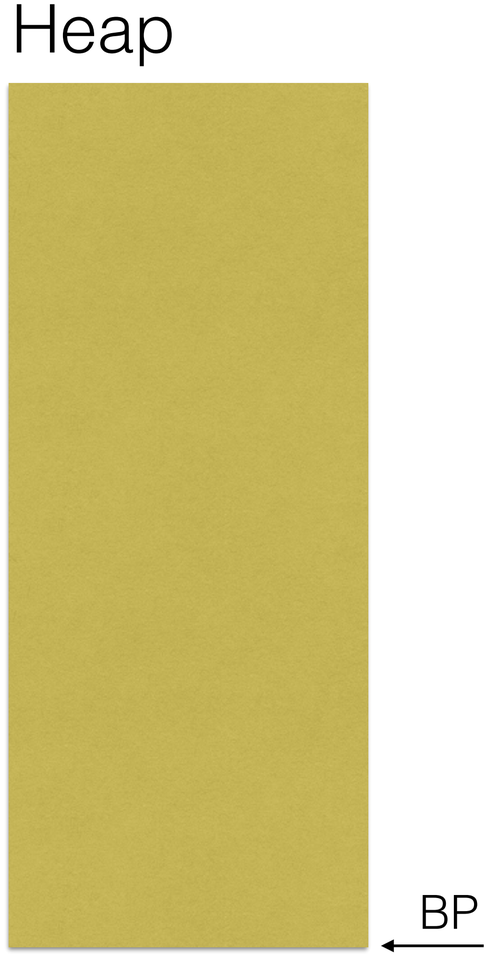
Dynamic Memory Allocation

- Bump pointer allocation
  - Pointer (BP) marks end of last allocation



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- Example

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void *p1 = malloc(sizeof(int));
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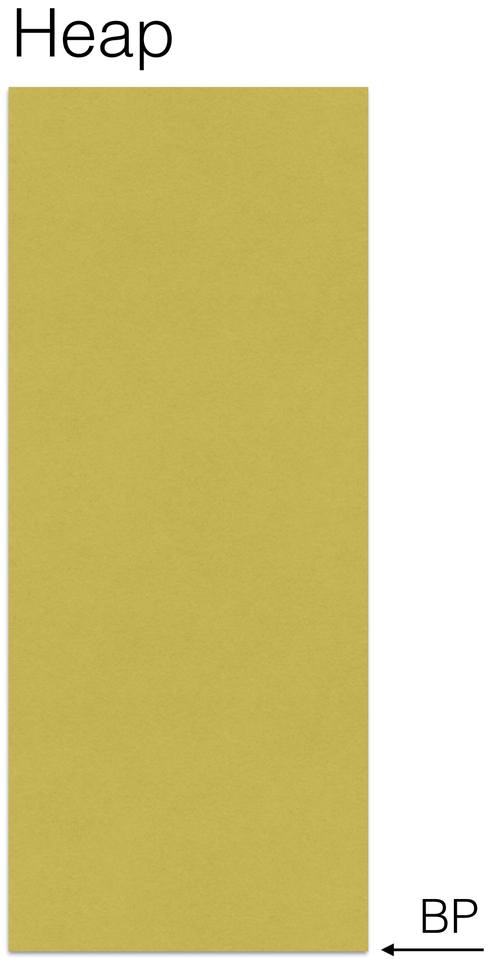

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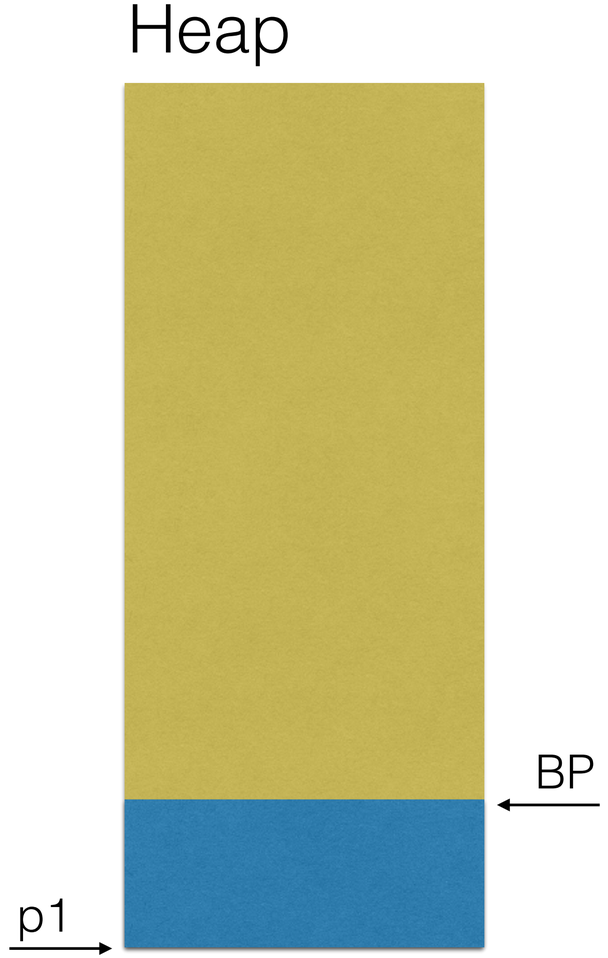

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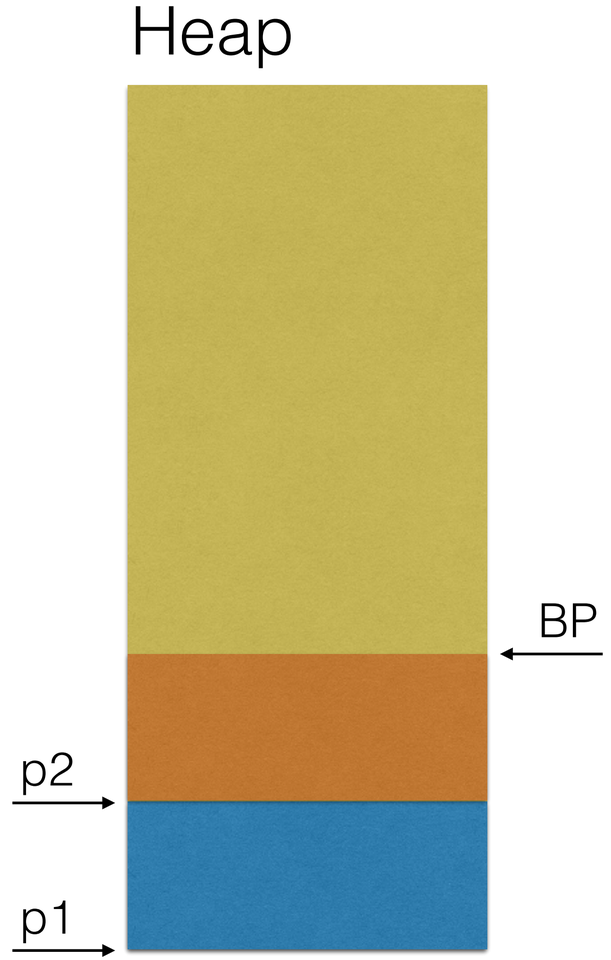
```



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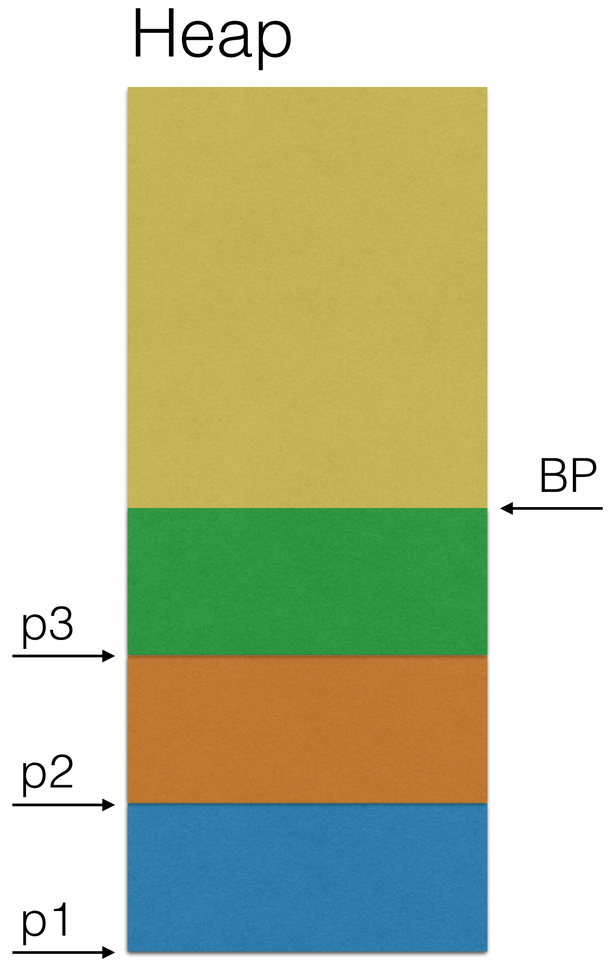

- Example

```
void *p1 = malloc(sizeof(int));
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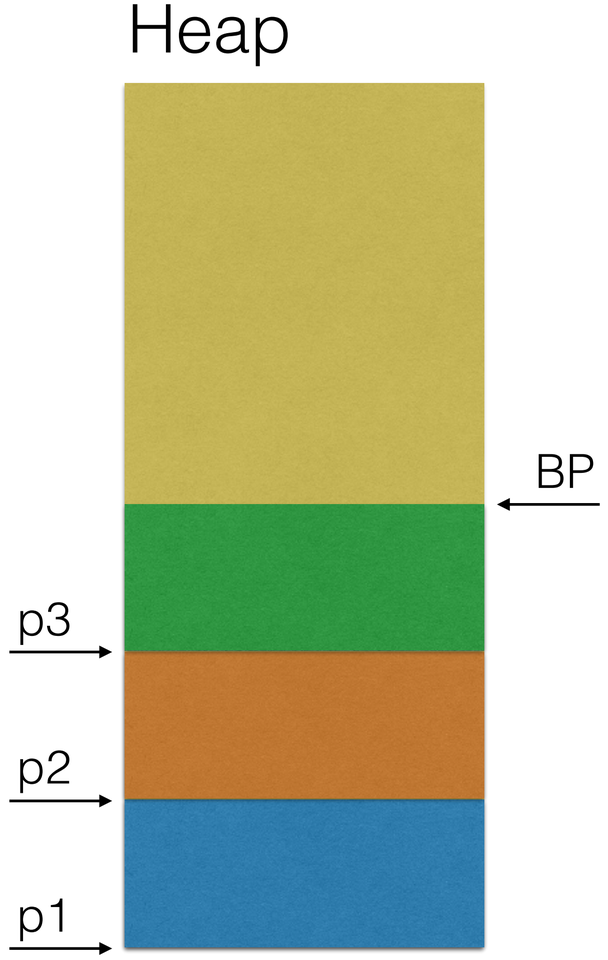

- Example

```
void *p1 = malloc(sizeof(int));
void *p2 = malloc(sizeof(int));
void *p3 = malloc(sizeof(int));
void *p4 = malloc(4*sizeof(int));
```

Dynamic Memory Allocation

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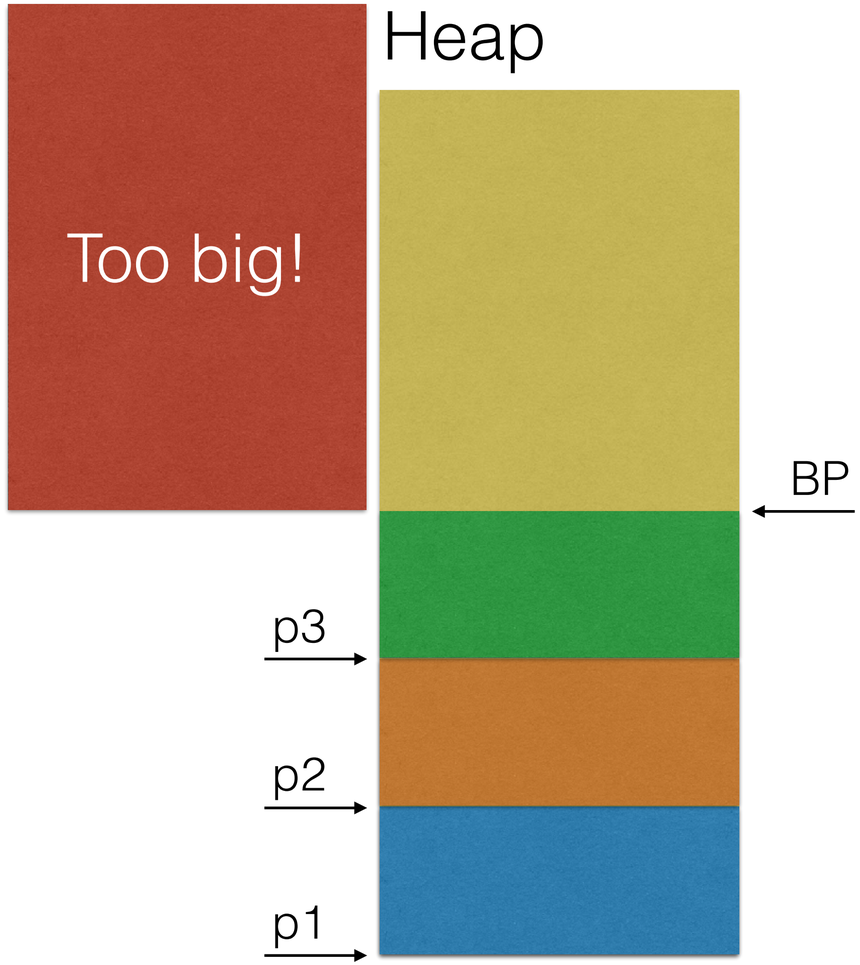

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Dynamic Memory Allocation

BOUND CHECKS

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Performance Overhead

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Allocation Folding

- Group allocations together

- Example

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[…]
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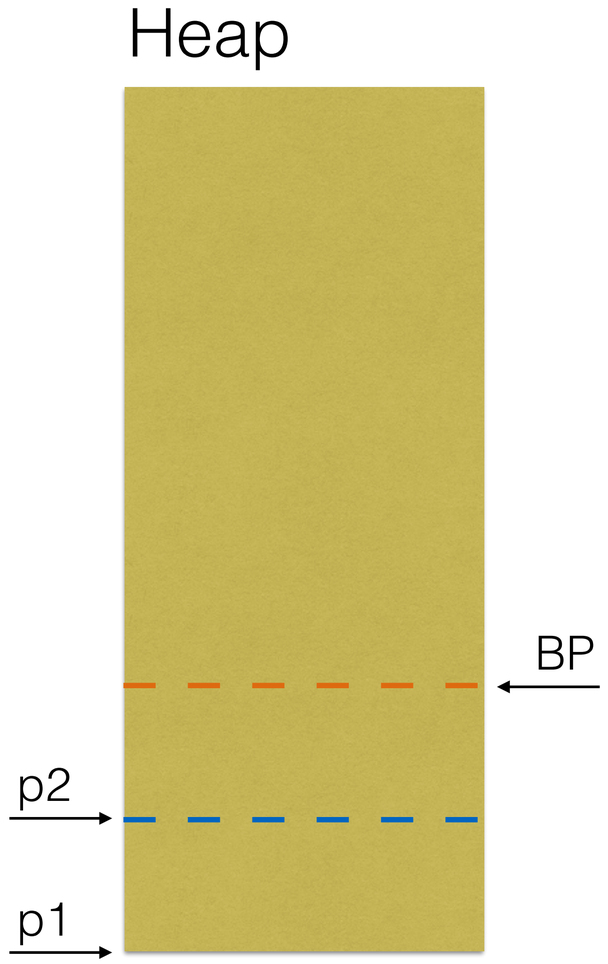

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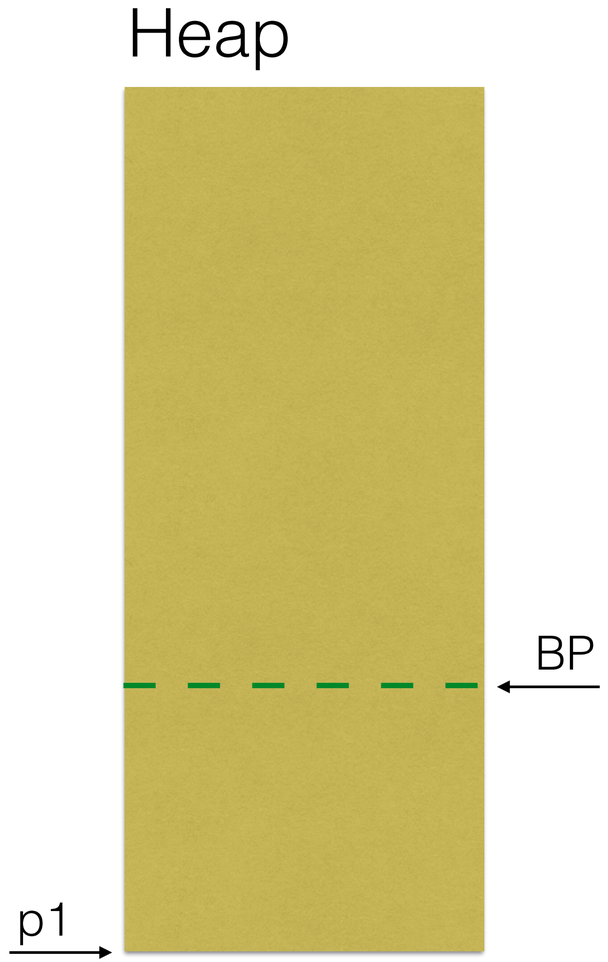

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void *p2 = malloc(sizeof(int));
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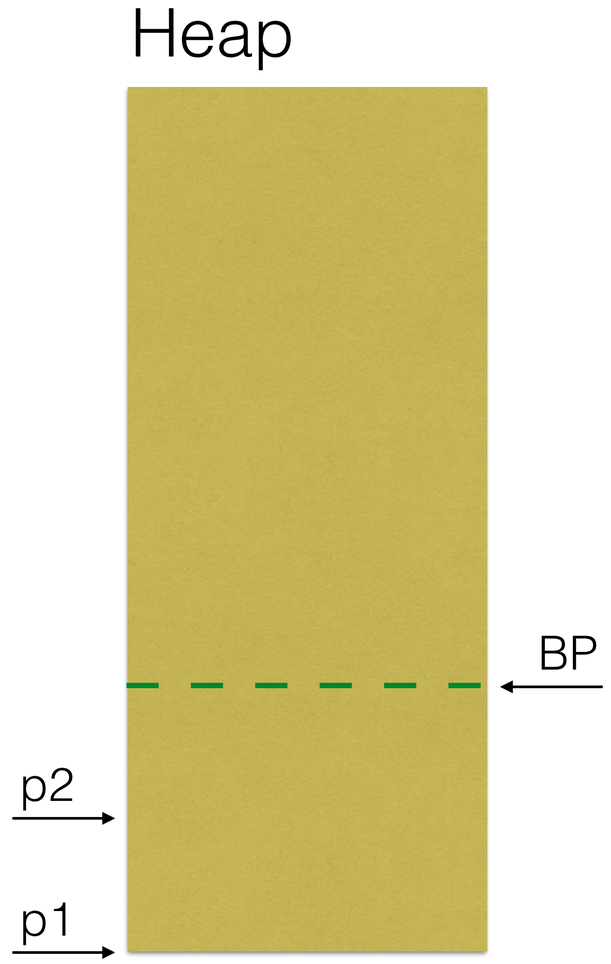
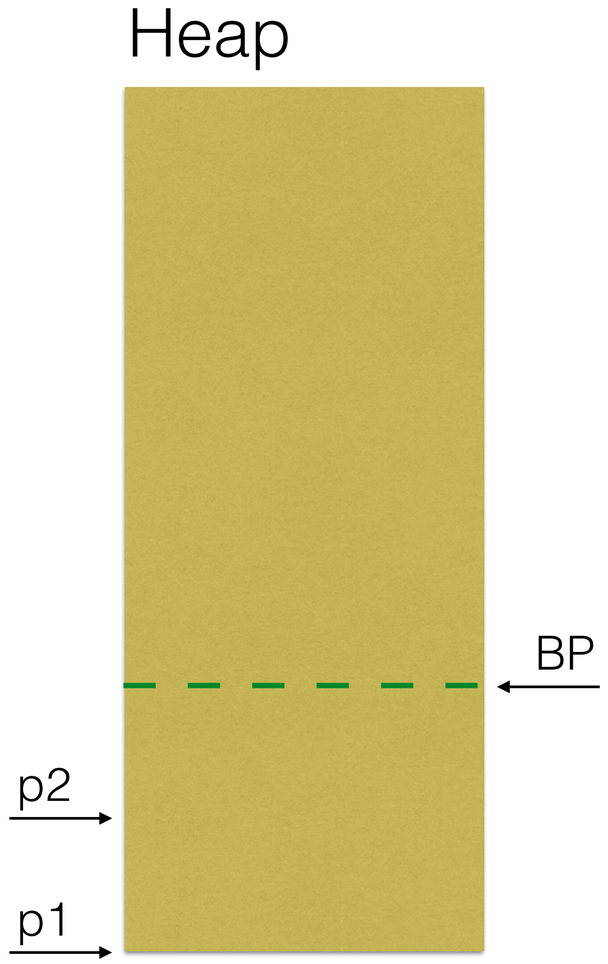


Allocation Folding

- Group allocations together

- Example

```
void *p1 = malloc(sizeof(int));
[…]    //be careful!
void *p2 = malloc(sizeof(int));
```



Invariant 1

Between two allocations A_1 and A_2, if no other operation that can move the object allocated at A_1 occurs, then space for the object allocated at A_2 could have been allocated at A_1 and then initialized at A_2, without ever having been observable to the garbage collector.

V8

- JavaScript virtual machine
- Open Source[1]
- C++
- Used in Google Chrome

[1] https://code.google.com/p/v8

Garbage Collector

- Generational
  - New generation
    - Semi-space strategy
    - Scavenger
  - Old generation
    - Mark and sweep collector
      - Depth-first search
      - 3 colors

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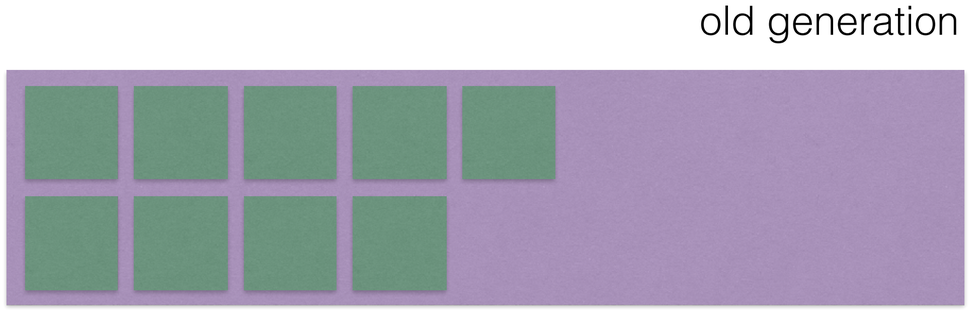

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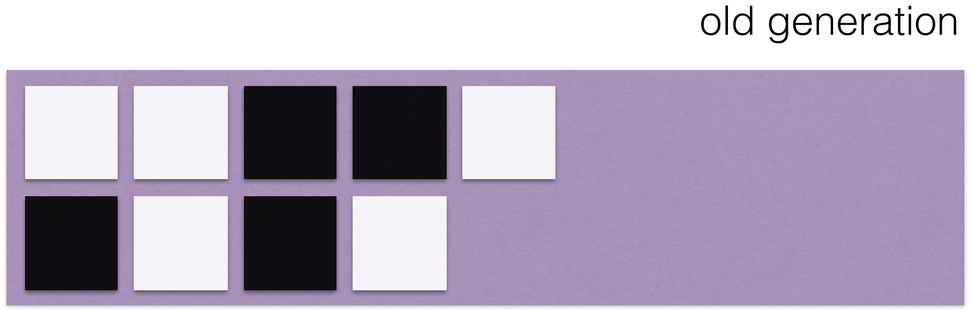

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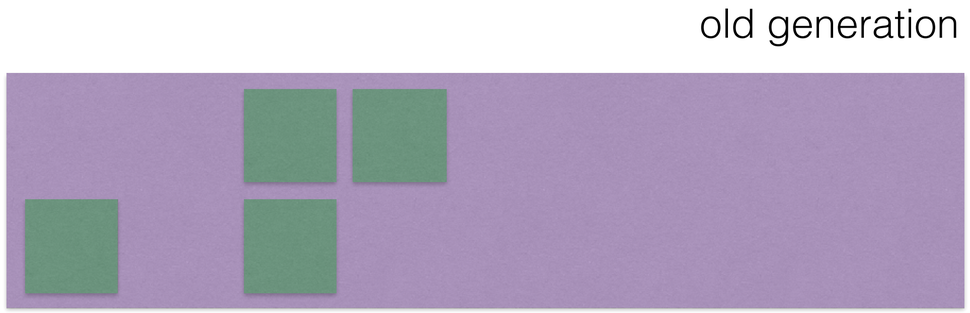

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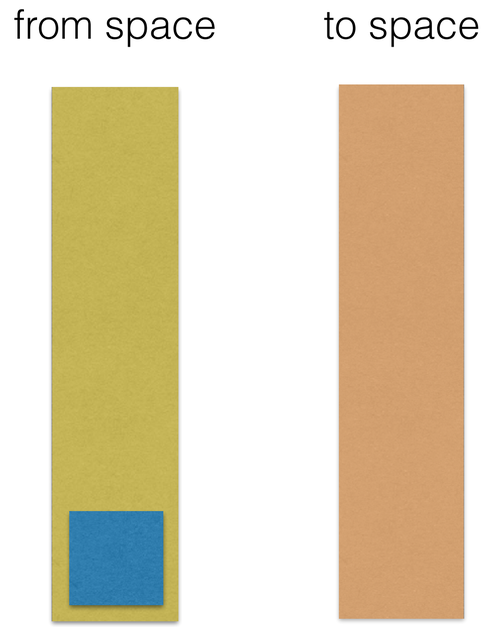

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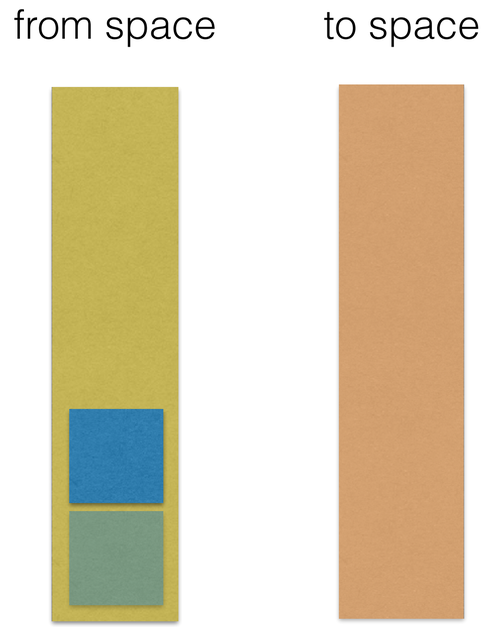

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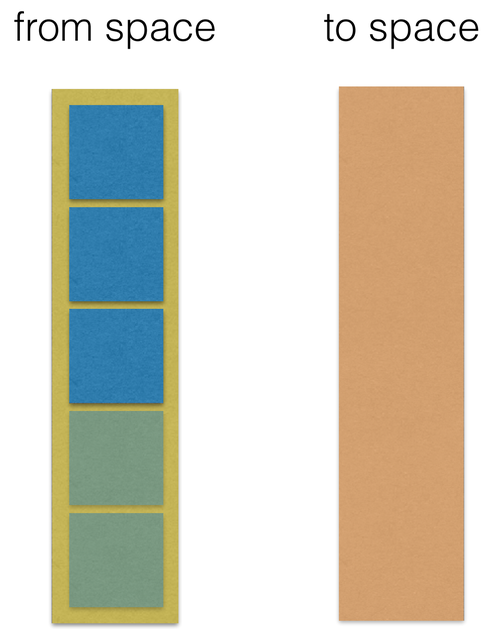

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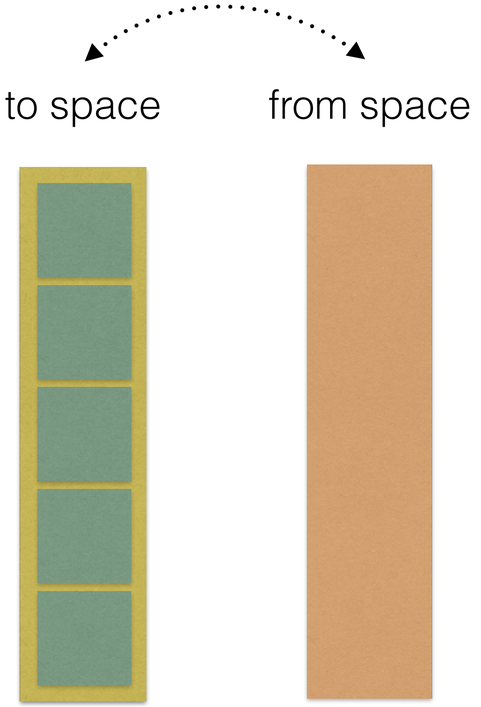

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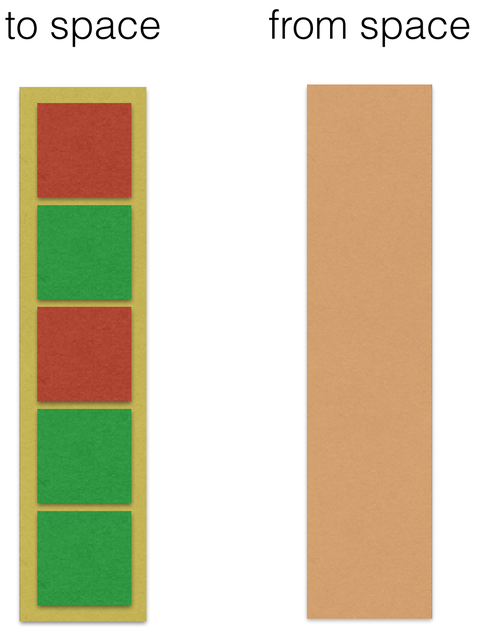

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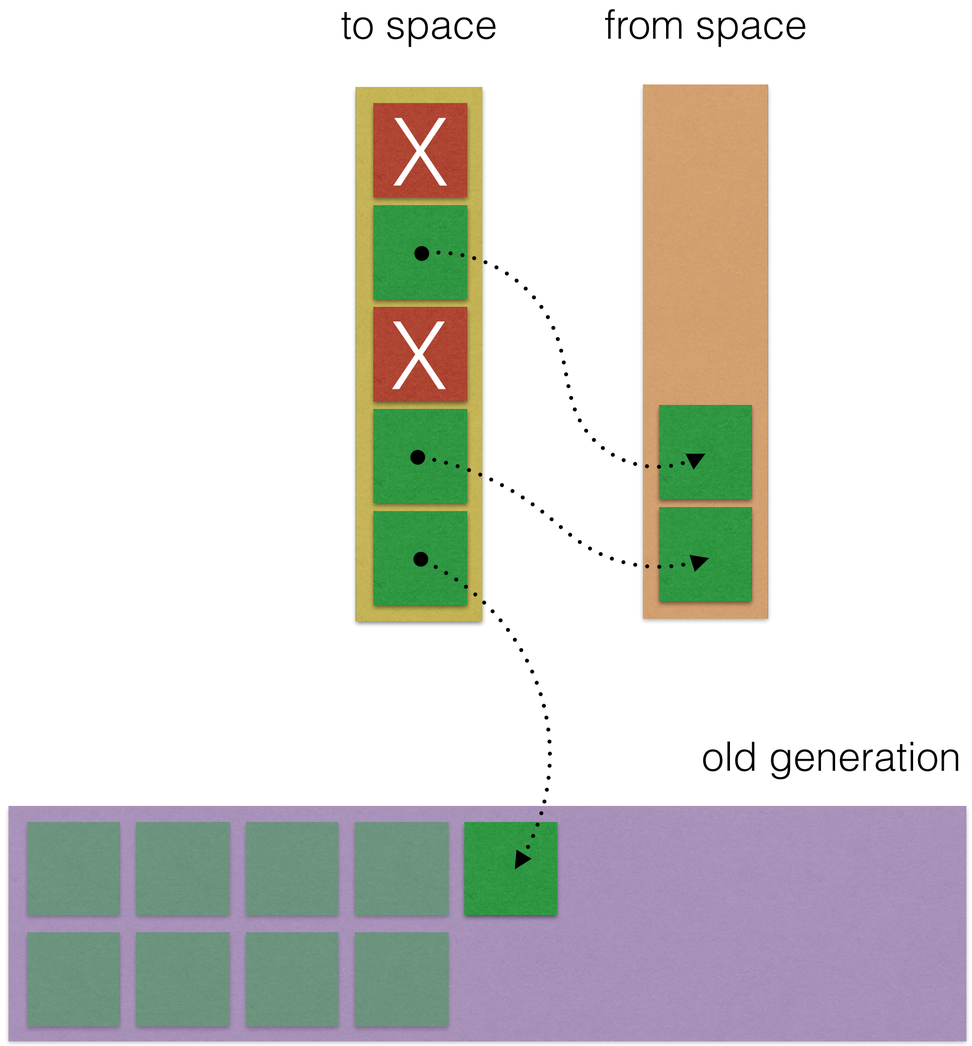

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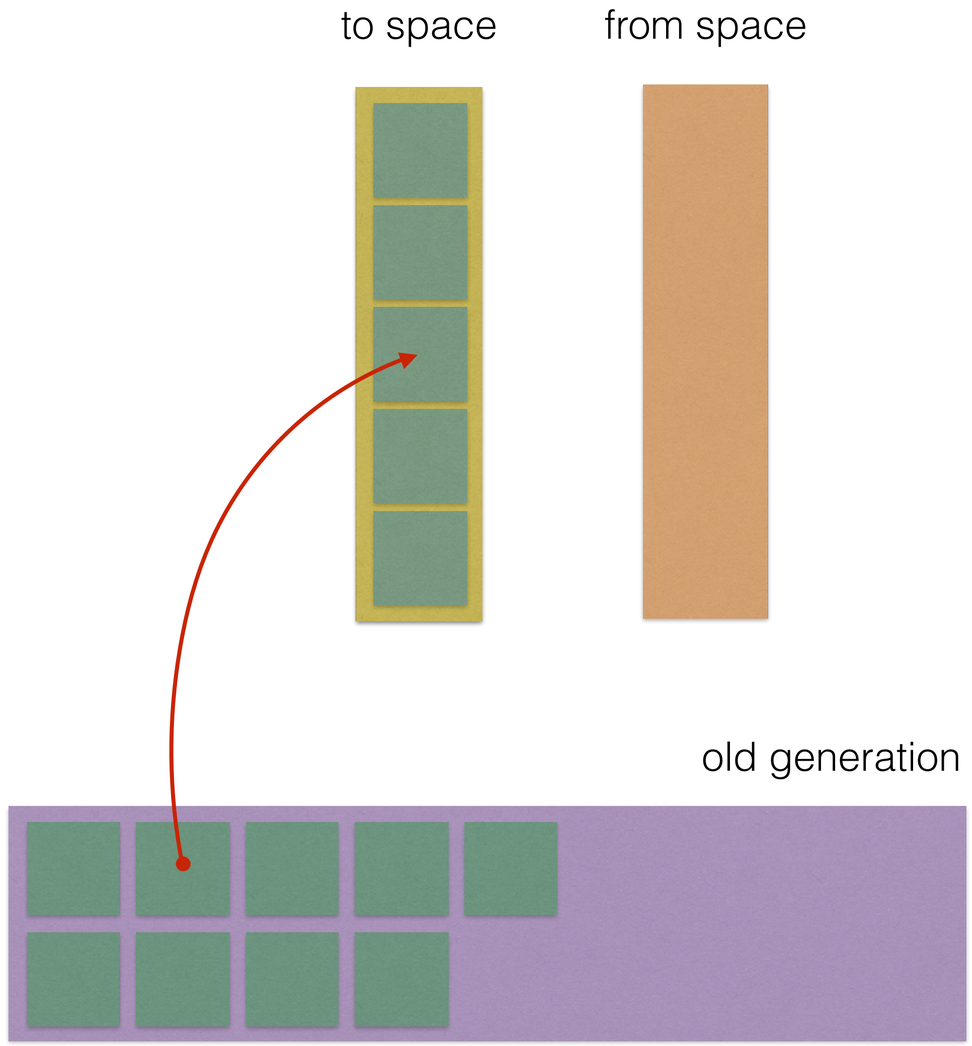

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- Write barriers
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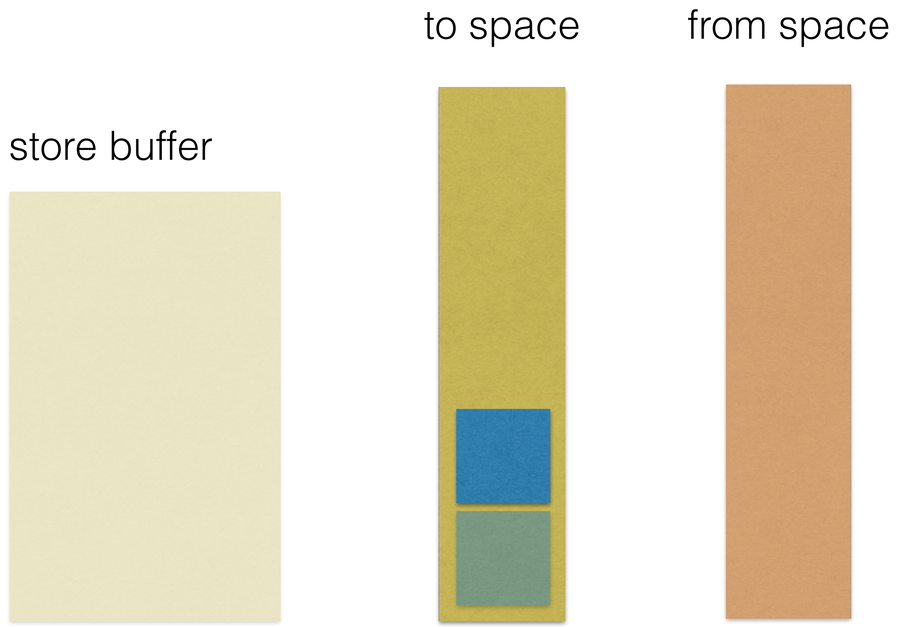

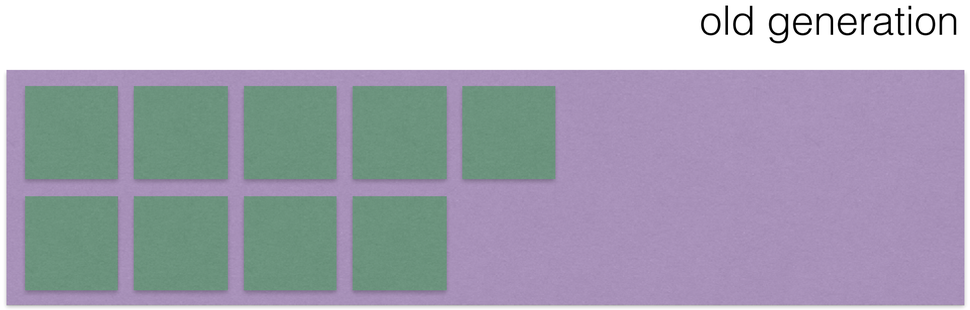

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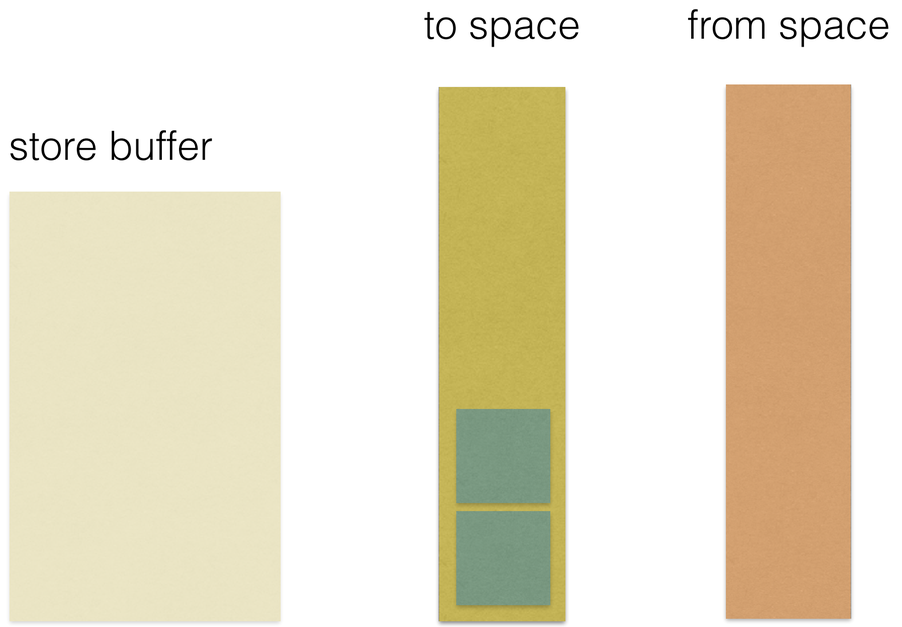

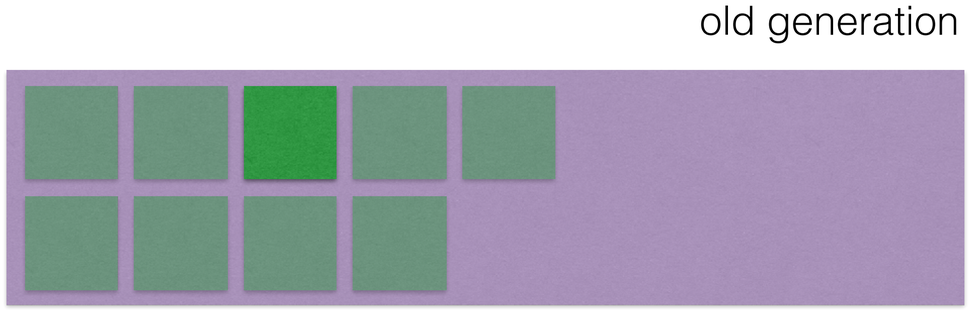

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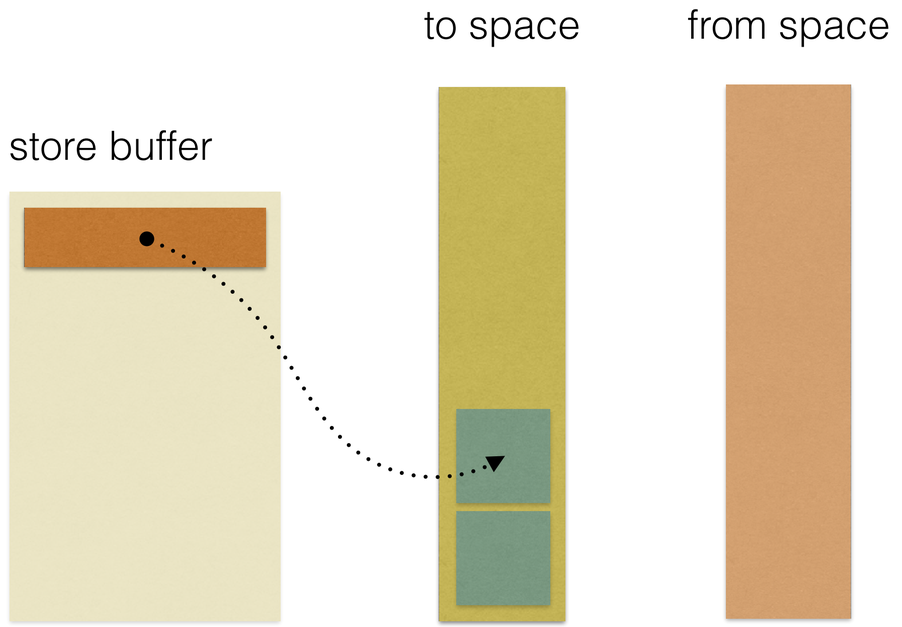

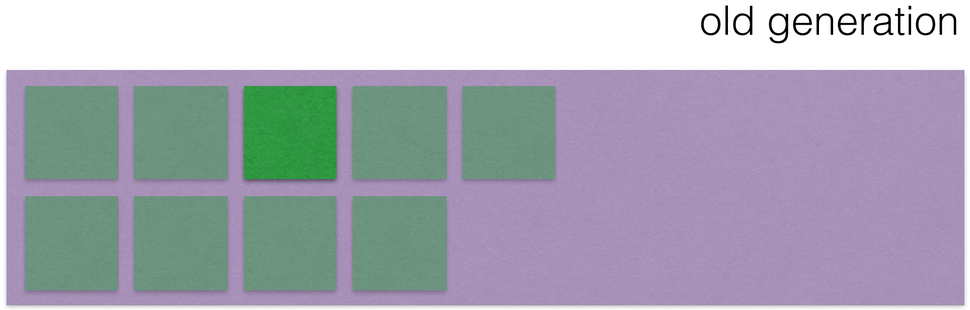

Compilers

- Full compiler
  - Compiles everything
  - Unoptimized code
- Optimizing Compiler (Crankshaft)
  - Intermediate representation (IR)
  - Several compiler optimizations
    - Global value numbering (GVN)

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Crankshaft IR Instruction	Dep	Chg
I_n = PARAMETER[K]		
I_n = CONSTANT[K]		
I_n = ARITH(I, I)		
I_n = LOAD[field](object)	Ψ	
I_n = STORE[field](object, value)		Ψ
I_n = ALLOC[space](size)	Λ	Λ
I_n = INNER[offset, size](alloc)		
I_n = CALL(I…)	*	*
I_n = PHI(I…)		
…		

Table 1: Simplified Crankshaft IR Instructions

Crankshaft IR (*Example*)

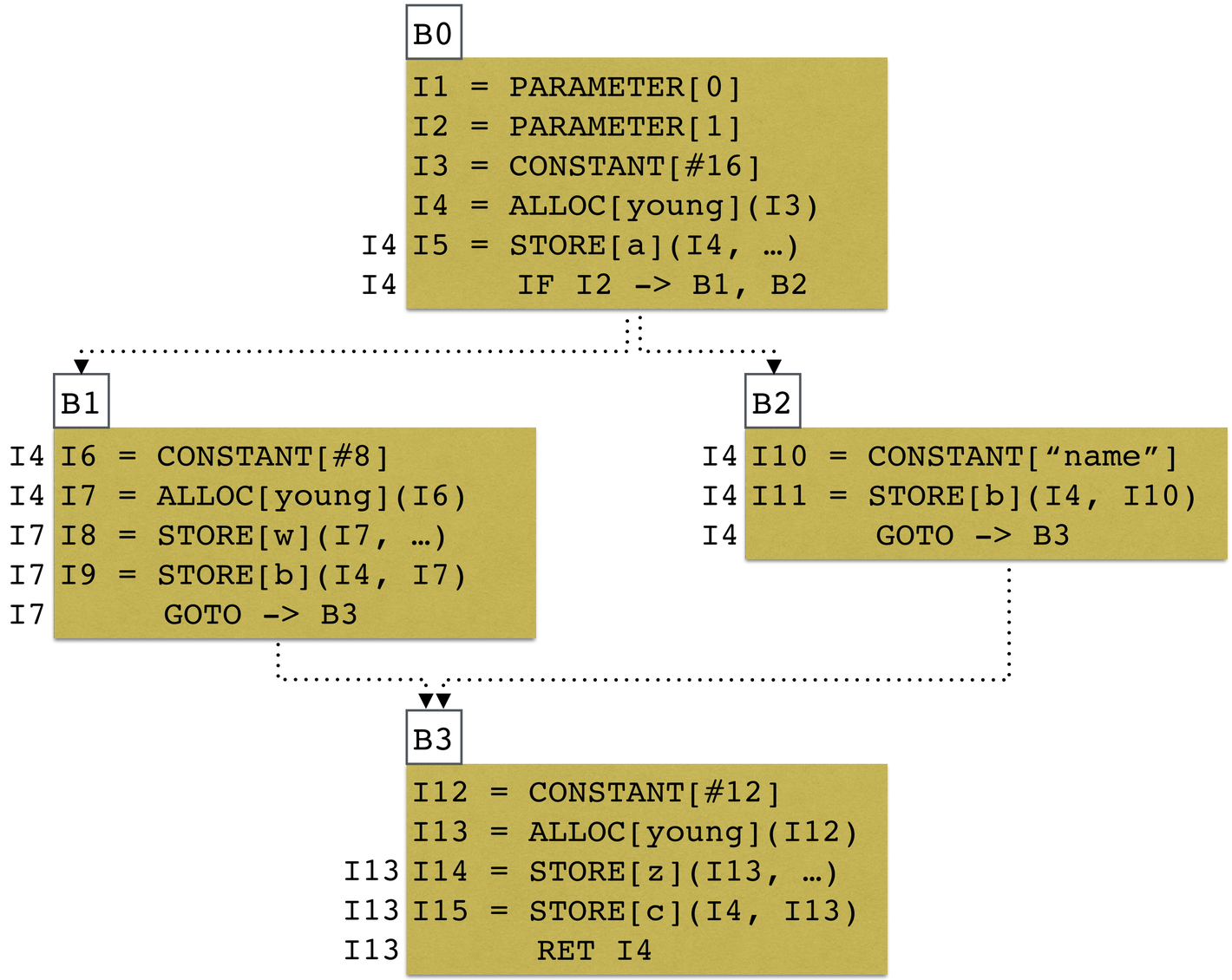

Figure 1: Control flow graph

Compilers

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Global Value Numbering (GVN)

- Eliminates redundant computations
- For pure operations
  - Arithmetic on primitives, math functions, etc.
  - Value numbering table
  - Example: `ARITH(`I_i`, `I_j`)`
    - If two `ARITH` instructions are value-equivalent (same operation and input values)
    - Second instruction is removed and reference to the first

Global Value Numbering (GVN)

- Important for allocation folding
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```
L1 = LOAD[field](Oi)
...
...
...
L2 = LOAD[field](Oi)
```

value numbering table

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```
L1 = LOAD[field](Oi)
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...
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Crankshaft IR Instruction	Dep	Chg
`In = LOAD[field](object)`	Ψ	
`In = STORE[field](object, value)`		Ψ

value numbering table

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  - Example:

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Ψ: L1 = LOAD[field](Oi)
   ...
   ...
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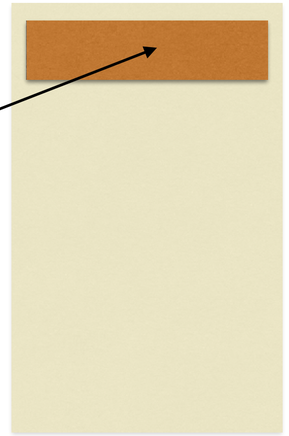

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   ...
Ψ: S1 = STORE[field](Oi, Vj)
   ...
Ψ: L2 = LOAD[field](Oi)
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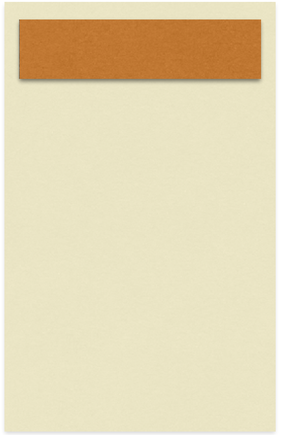
- Important for allocation folding
- For impure operations
  - May be effected by side-effects
  - Example:

```
Ψ: L1 = LOAD[field](Oi)
   ...
Ψ: S1 = STORE[field](Oi, Vj)
   ...
Ψ: L2 = LOAD[field](Oi)
```

Crankshaft IR Instruction	Dep	Chg
`In = LOAD[field](object)`	Ψ	
`In = STORE[field](object, value)`		Ψ

value numbering table



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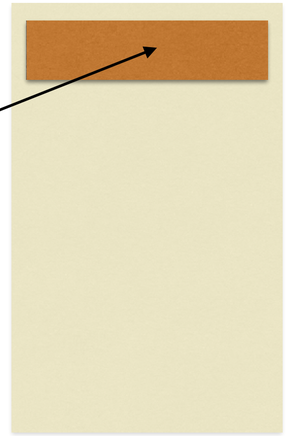


Allocation Folding Based on Dominance

Daniel Clifford, Hannes Payer, Michael Starzinger and Ben L. Titzer

International Symposium on Memory Management (ISMM) 2014

presented by Thomas Hütter

Concurrency & Memory Management Seminar 2015

Univ.- Prof. Dr. Christoph Kirsch

Department of Computer Sciences
University of Salzburg

Definition 1 (*ε-dominance*)

For a given effect ε, instruction D ε-dominates instruction I if and only if D occurs on every path from the function entry to I, and no path from D to I contains another instruction D' ≠ D that changes ε.

Predicate 1 (*Load Elimination*)

A load L_2=LOAD[$field_j$](O_i) *can be replaced with* L_1=LOAD[$field_j$](O_i) *if* L_1 *Ψ-dominates* L_2.

Definition 2 (*ε-dominator*)

For a given effect ε, instruction D is the ε-dominator of instruction I if and only if D ε-dominates I and D changes ε.

Allocation Folding

- `ALLOC`
  - Allocates a contiguous chunk of memory
- `INNER`
  - Computes effective address of a sub-region within an allocated chunk of memory

Crankshaft IR Instruction	Dep	Chg
I_n = ALLOC[space](size)	∧	∧
I_n = INNER[offset, size](alloc)		

Predicate 3 (*Allocation Folding on Crankshaft IR*)

Allocations A_1=`ALLOC[s](`K_1`)` *and* A_2=`ALLOC[s](`K_2`)` *are candidates for allocation folding if* A_1 *is the* Λ*-dominator of* A_2.

Allocation Folding (*Example*)

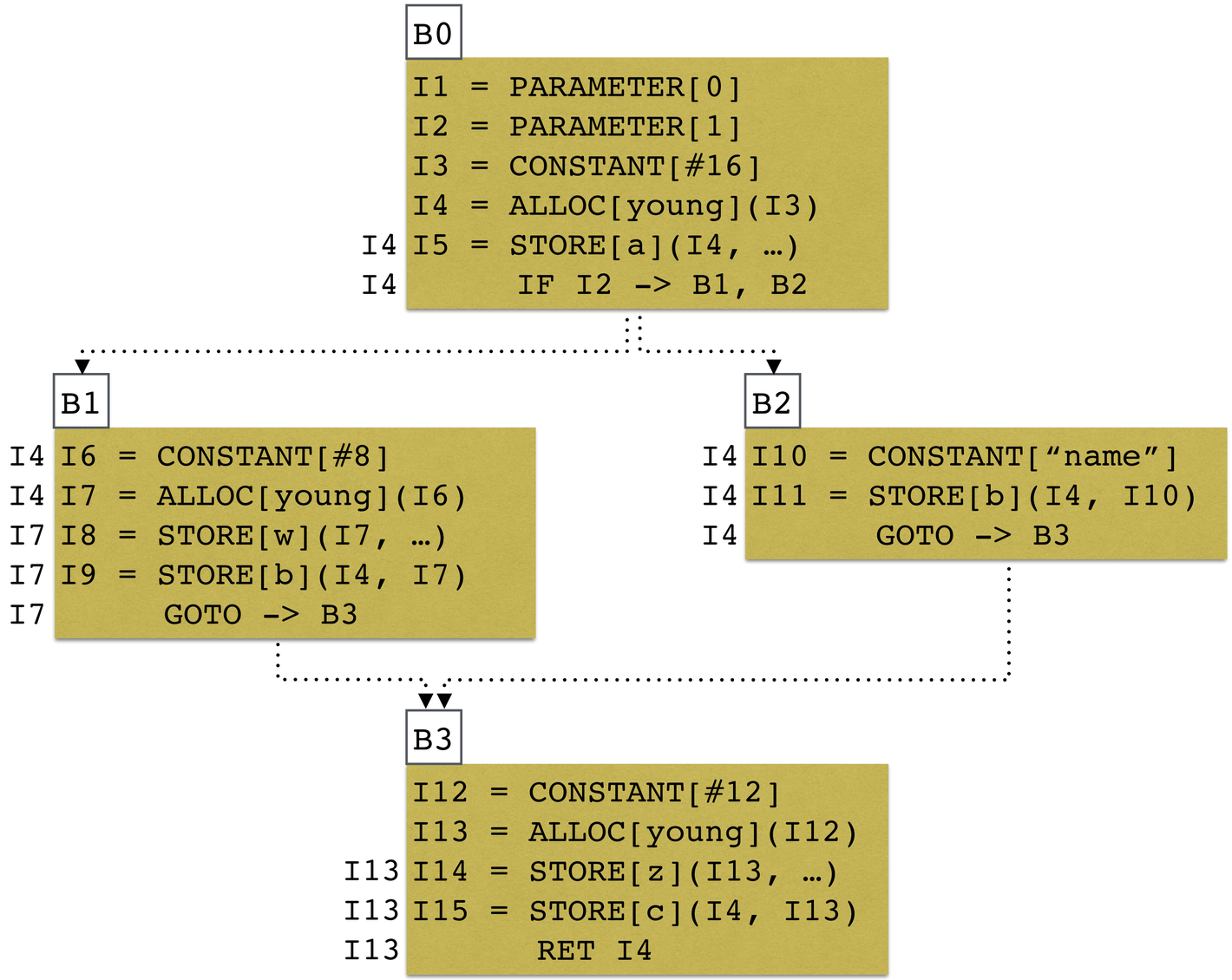


Figure 1: Control flow graph befor allocation folding.

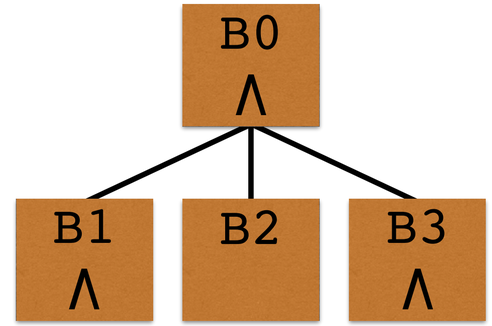
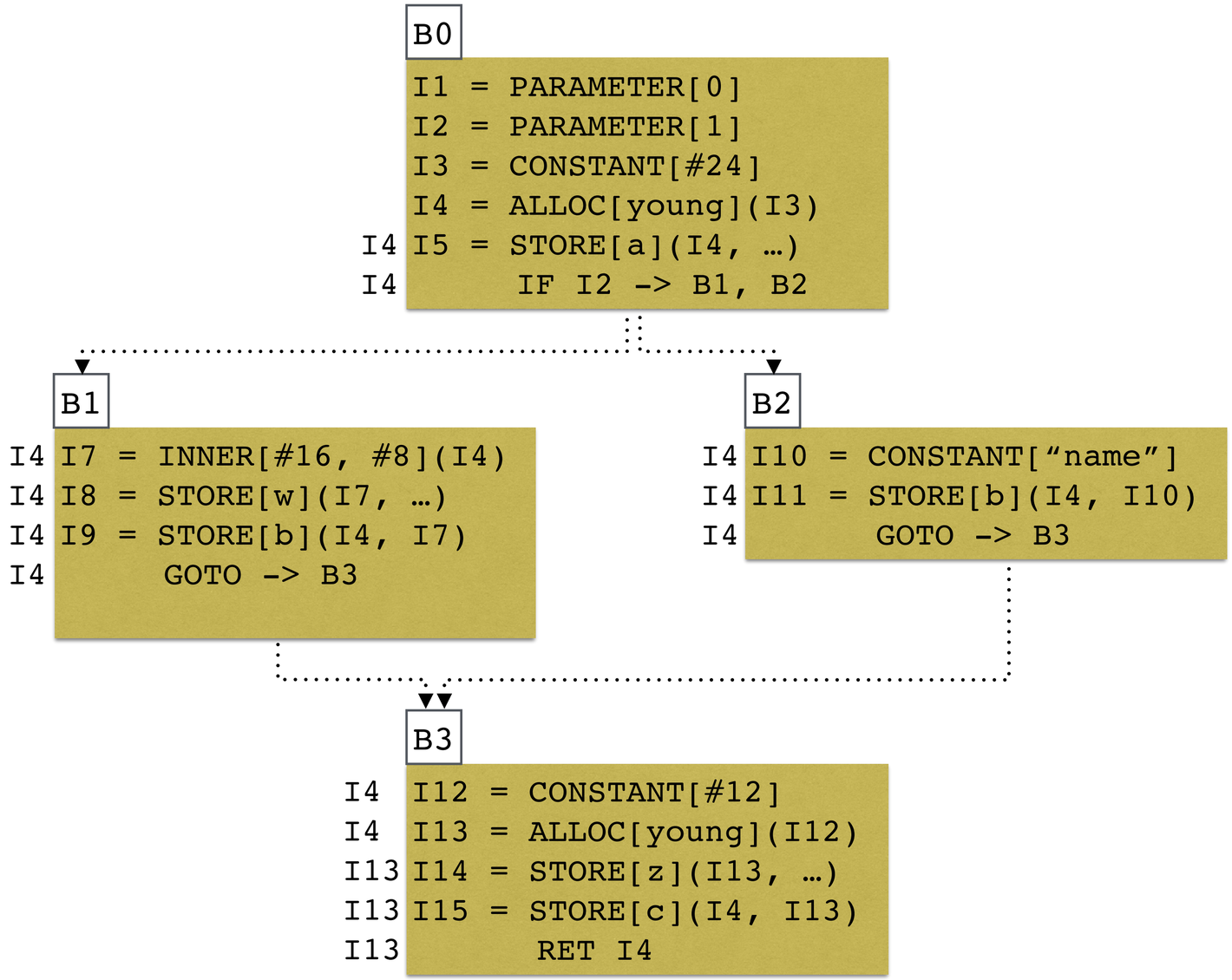


Figure 1a: Dominator tree.

Allocation Folding (*Example*)



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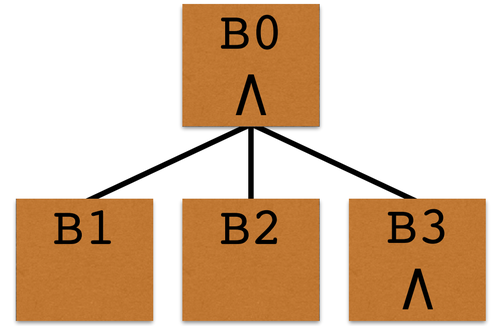


Figure 1a: Dominator tree.

Allocation Folding (*Example*)

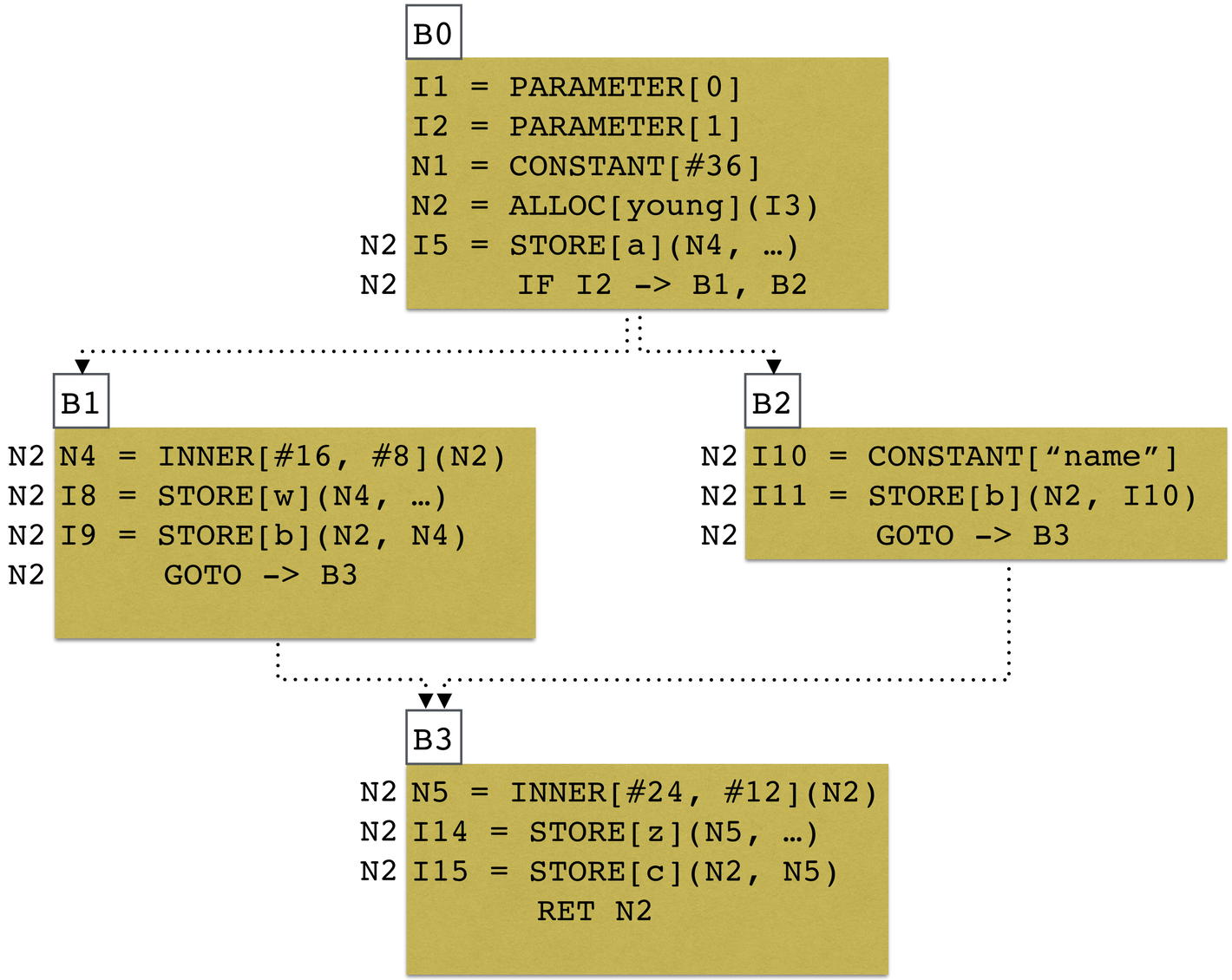


Figure 2: Control flow graph after allocation folding.

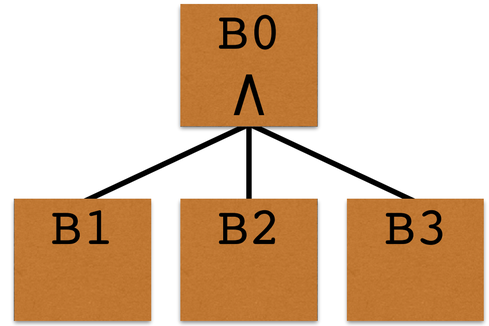


Figure 2a: Dominator tree.

Experiments

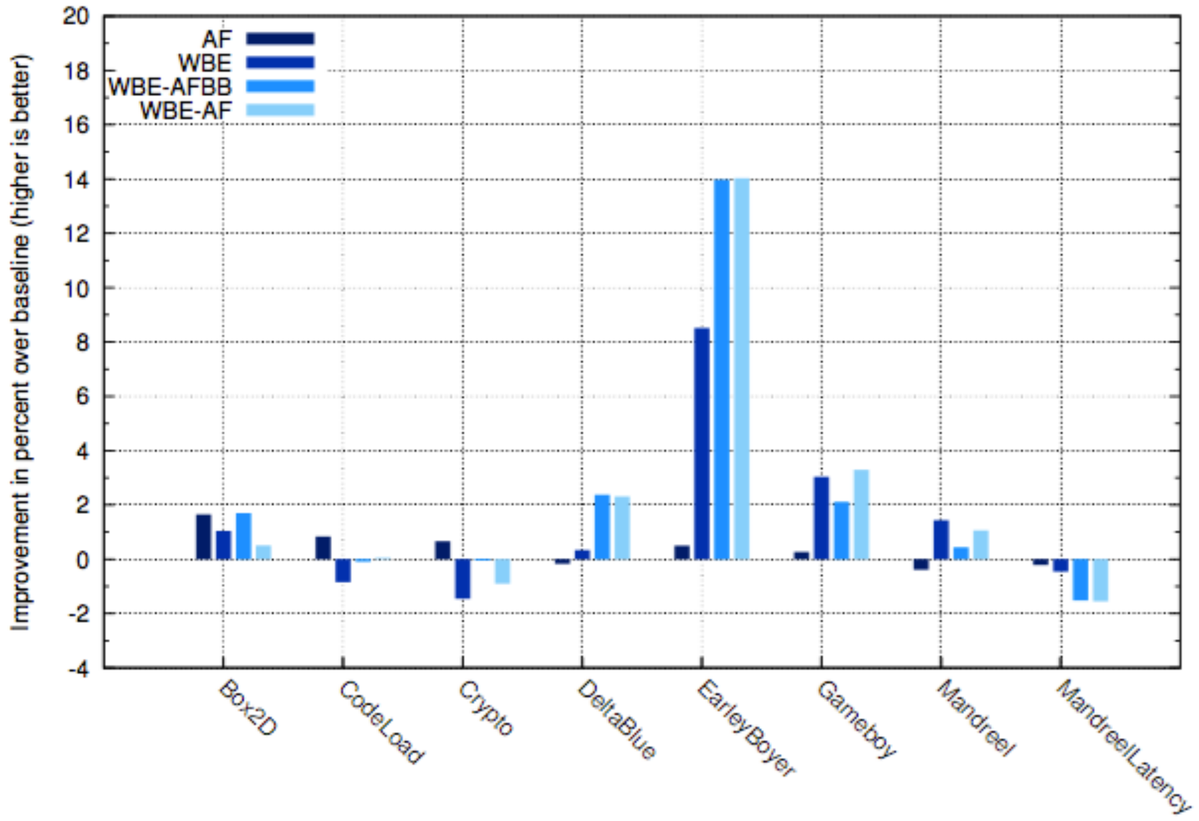
- v8 revision r18926
- X64 Server
  - Intel Core i5-2400 quad core 3.10GHz CPU
  - 80 GB main memory
  - Linux
- No relevant differences on IA32 and ARM
- Average of 20 repetitions

Experiments

- Benchmarks
  - Octane 2.0
  - Kraken 1.1
  - Four other hand selected benchmark

- Naming
  - Allocation folding (AF)
  - Write barrier elimination (WBE)
  - Write barrier elimination and allocation folding on basic blocks (WBE-AFBB)
  - Write barrier elimination and allocation folding (WBE-AF)

Throughput



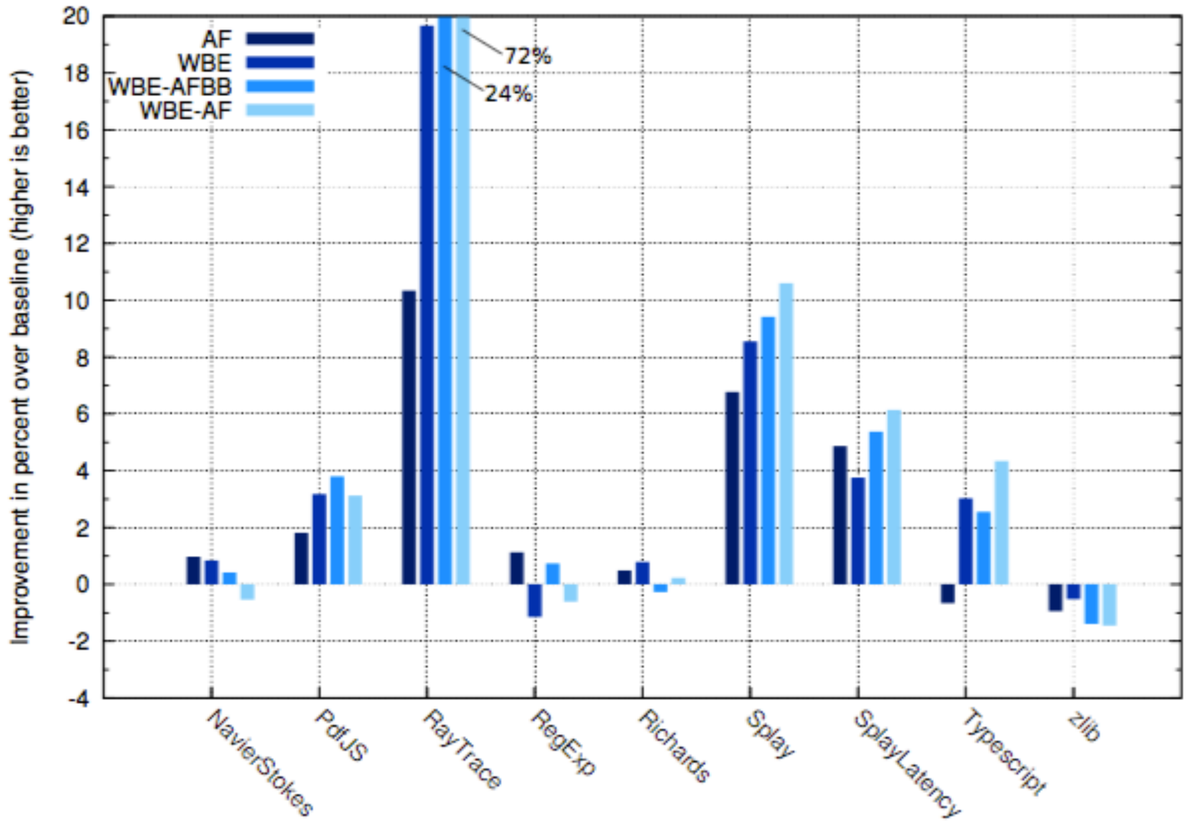


Figure 3: Improvement in percent of all configurations over the baseline on the Octane suite running on X64.

Throughput

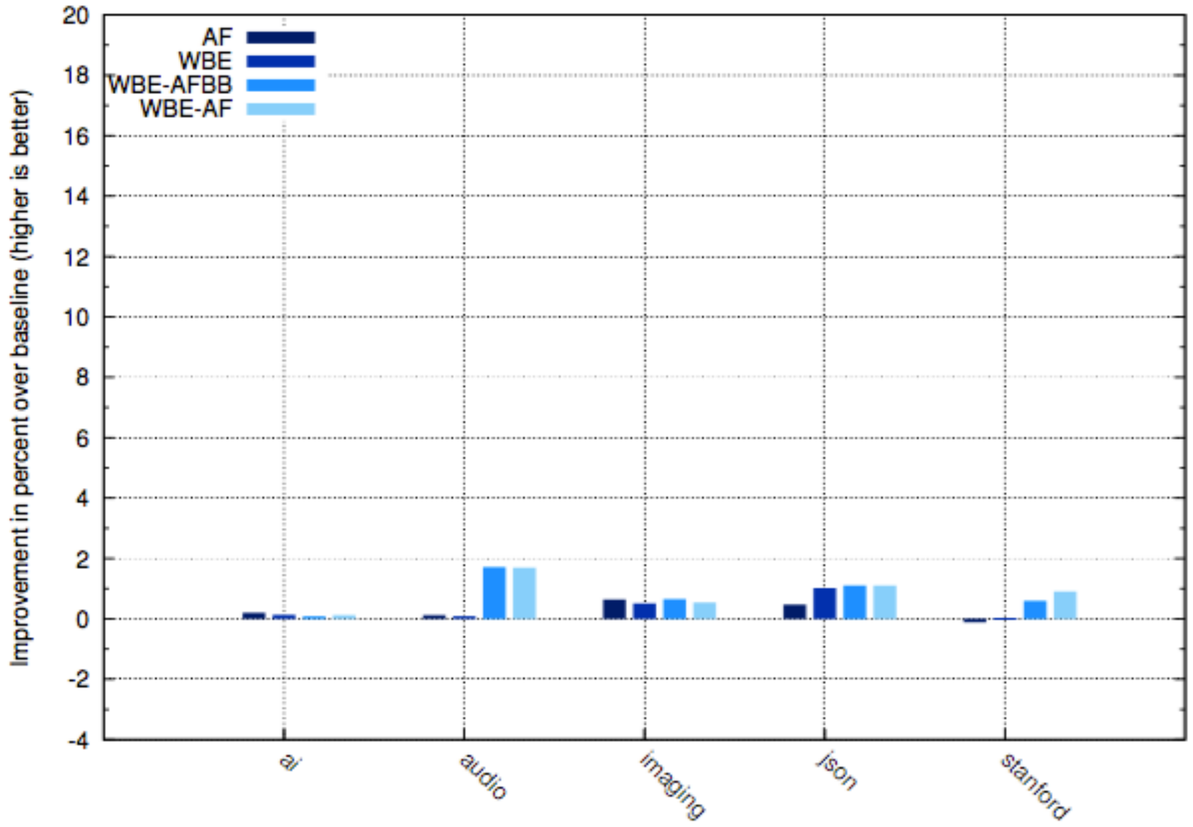


Figure 4: Improvement in percent of all configurations over the baseline on the Kraken suite running on X64.

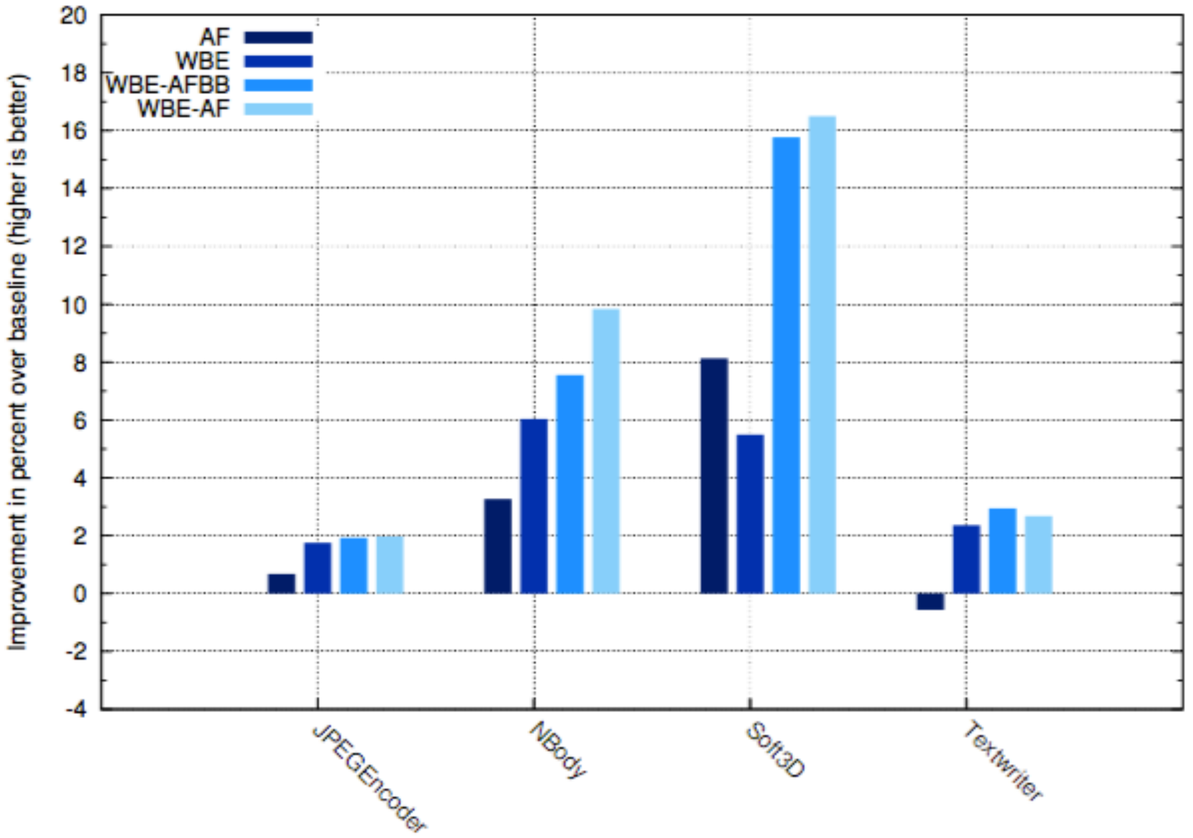


Figure 5: Improvement in percent of all configurations over the baseline on the hand-selected benchmarks running on X64.

Folded Allocations

Benchmark	AFBB [%]	AF [%]
Box2D	21	35
CodeLoad	28	28
Crypto	33	42
DeltaBlue	37	47
EarleyBoyer	26	42
Gameboy	3	3
Mandreel	38	38
Mandreel Latency	38	38
NavierStokes	18	18
PdfJS	29	31
RayTrace	11	65
RegExp	27	27
Richards	26	65

Benchmark	AFBB [%]	AF [%]
Splay	22	40
SplayLatency	22	40
Typescript	6	12
zlib	82	82
ai	25	25
audio	37	38
imaging	0	0
json	0	0
standford	23	24
JPEGEncoder	18	55
NBody	76	88
Soft3D	56	58
Textwriter	8	17

Table 2, 3, 4: Static proportion of folded allocation instructions in Octane, Kraken and hand-selected benchmarks.

Allocation Group Utilization

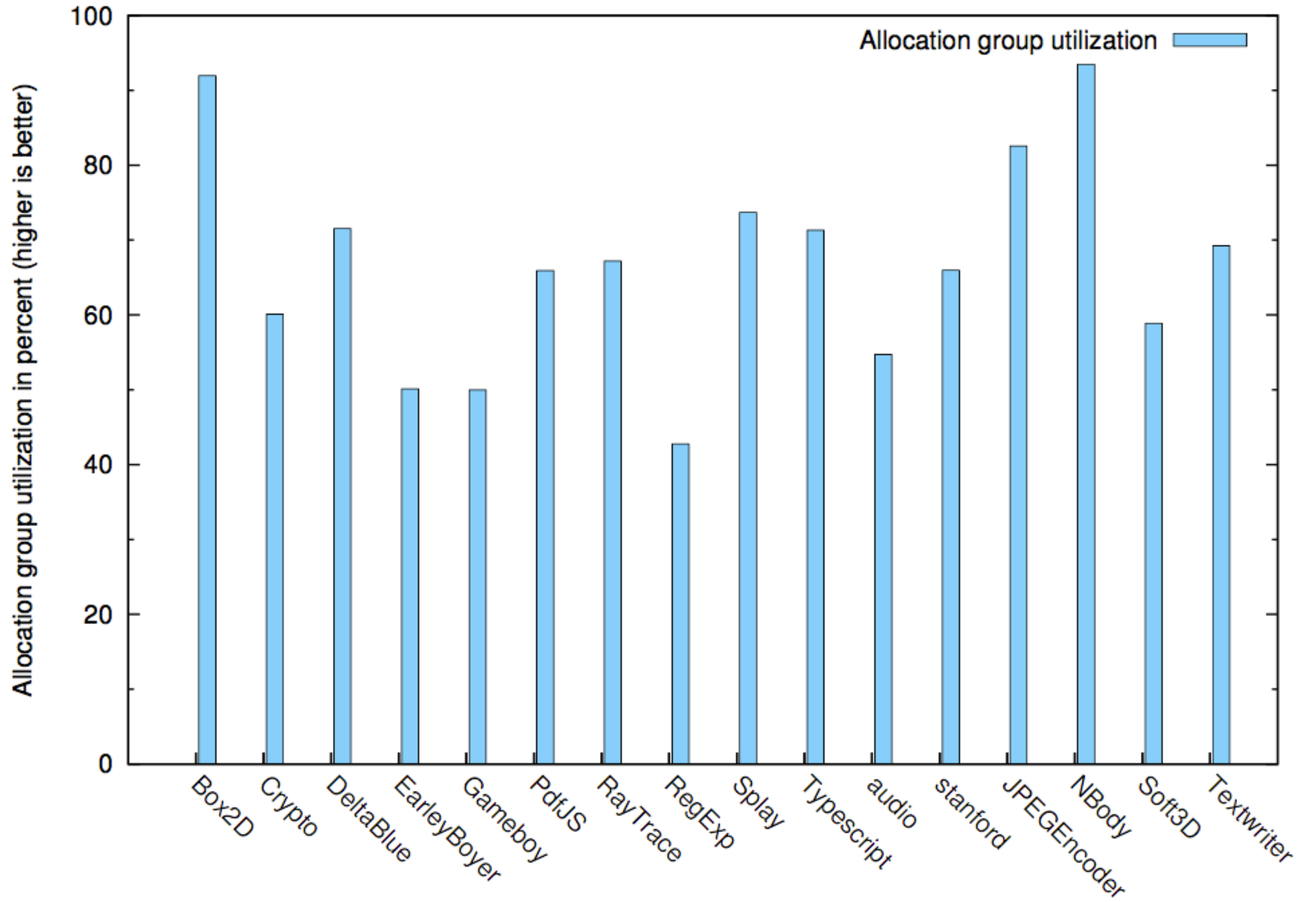


Figure 6: Allocation group utilization on X64.

Garbage Collection Overhead

	Baseline, WBE, WBE-AFBB (no fragmentation)			AF, WBE-AF (fragmentation)		
Benchmark	#Minor GCs	#Major GCs	GC time in ms	#Minor GCs	#Major GCs	GC time in ms
Box2D	111	5	99.37	111	5	100.97
CodeLoad	14	5	137.45	14	5	136.22
Cyrpto	62	0	2.25	69	0	1.5
DeltaBlue	585	0	44.57	587	0	45.11
EarleyBoyer	856	0	770.58	856	0	763.82
Gameboy	37	18	112.99	37	19	116.51
Mandreel	106	6	12.84	106	6	12.91
MandreelLatency	106	6	12.84	106	6	12.91
NavierStokes	16	0	2.18	16	0	2.26
PdfJS	555	26	772.54	555	29	813.28
RayTrace	2599	0	18.5	2610	0	22.11
RegExp	959	0	20.49	956	0	18.91
Richards	63	0	0.56	63	0	0.56
Splay	311	194	416.69	313	194	419.1
SplayLatency	311	194	416.69	313	194	419.1
Typescript	51	6	444.77	51	6	449.11
zlib	1	1	2.41	1	1	2.35

	Baseline, WBE, WBE-AFBB (no fragmentation)			AF, WBE-AF (fragmentation)		
Benchmark	Minor GCs	Major GCs	GC time in ms	Minor GCs	Major GCs	GC time in ms
ai	4	1	6.55	4	1	6.49
audio	42	6	18.37	43	6	18.31
imaging	2	4	6.45	2	4	6.33
json	21	2	4.16	21	2	4.26
stanford	45	4	16.96	45	4	16.97

	Baseline, WBE, WBE-AFBB (no fragmentation)			AF, WBE-AF (fragmentation)		
Benchmark	Minor GCs	Major GCs	GC time in ms	Minor GCs	Major GCs	GC time in ms
JPEGEncoder	18	1	17.89	18	1	17.51
NBody	597	0	0.31	620	0	0.31
Soft3D	437	0	57.44	493	0	105.67
TextWriter	2213	0	6.28	2230	0	10.13

Table 8, 9, 10: Number of minor collections, major collections, and total garbage collection time in ms with and without allocation folding in the Octane, Kraken Suite and hand-selected benchmarks on X64.

Thank you for your attention