A *Compact* Bytecode Format for **JavaScriptCore**

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Safari

Agenda

- High level overview
- Old bytecode format
- New bytecode format
- Memory comparison
- Type safety improvements

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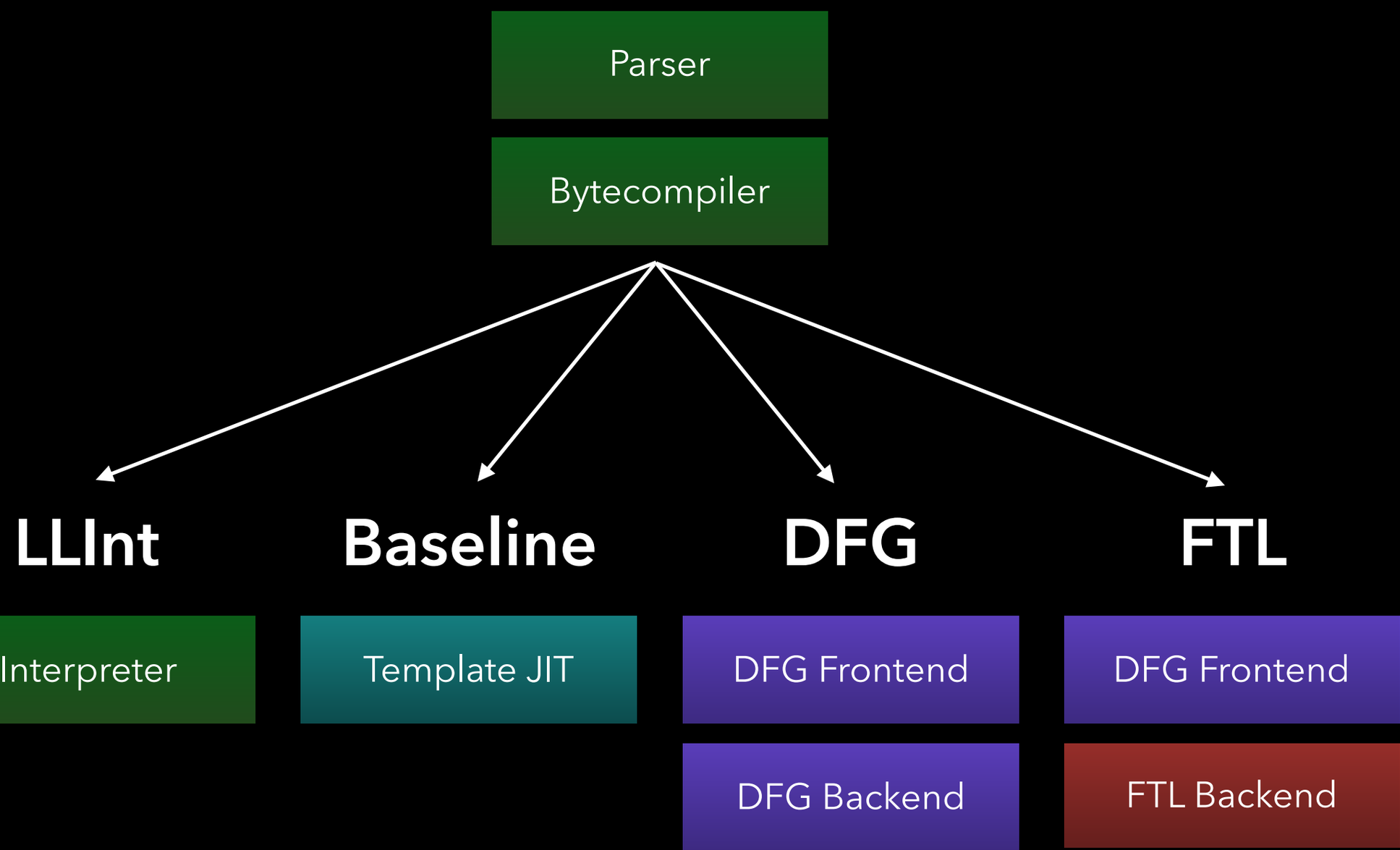
Parser
Bytecompiler
LLInt
Baseline
DFG
FTL
Interpreter
Template JIT
DFG Frontend
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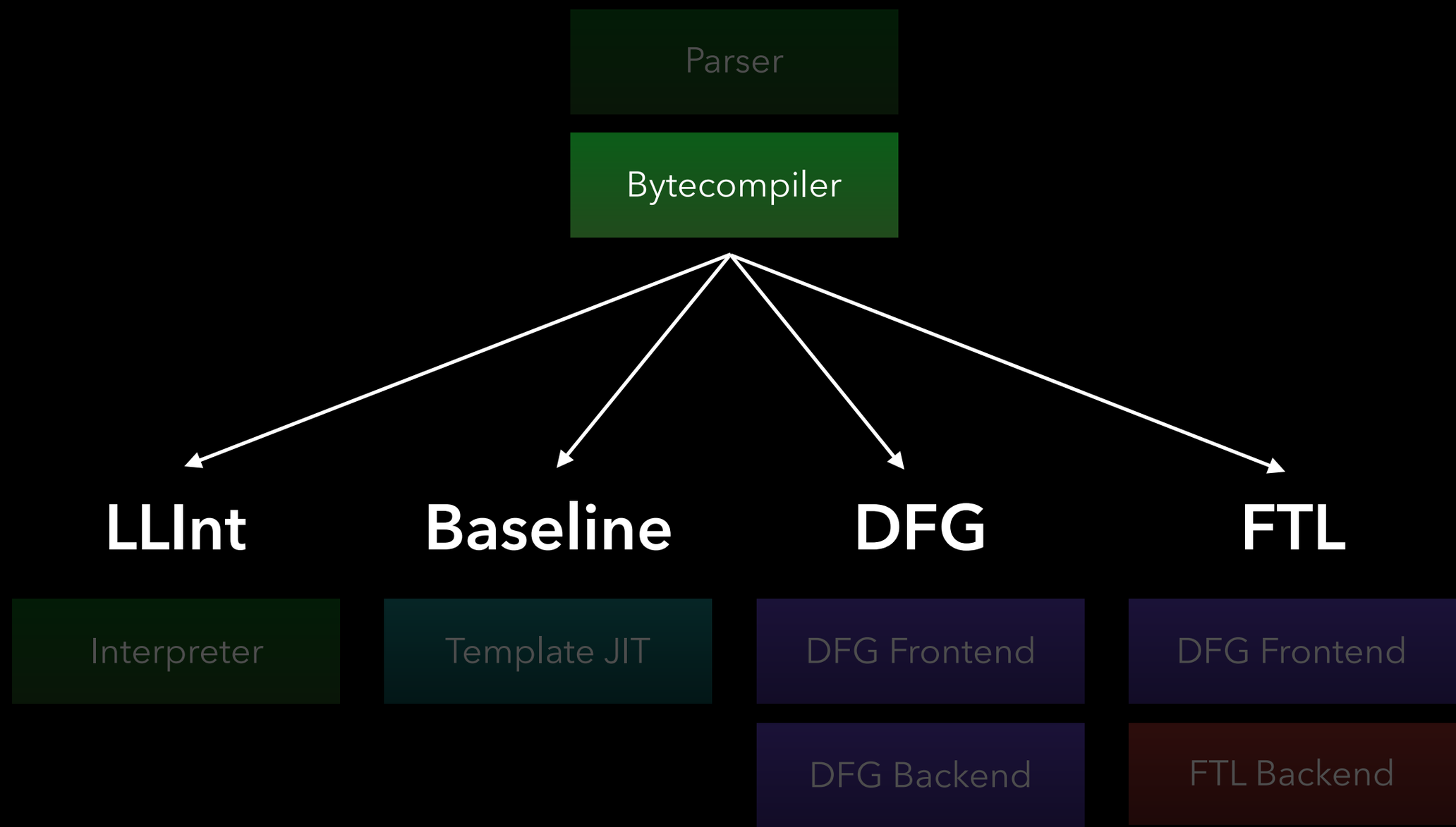
DFG Backend
FTL Backend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Bytecode Goals

- Memory efficiency
- Cacheable

Bytecode

```
// double.js
function double(a) {
    return a + a;
}
double(2);
```

```
$ jsc -d double.js
```

Bytecode

```
[ 0] enter
[ 1] get_scope     loc4
[ 3] mov           loc5, loc4
[ 6] check_traps
[ 7] add           loc7, arg1, arg1,
                     OperandTypes(126, 126)
[13] ret           loc7
```

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Old Bytecode Format

- Used too much memory
- The instruction stream was writable
- It had optimizations that were no longer beneficial

Old Bytecode Format

- Unlinked Instructions
  - Compact
  - Optimized for storage
- Linked Instructions
  - Inflated
  - Optimized for execution

Unlinked Instruction

1 byte	1 byte	1 byte	1 byte	2 bytes
op_add 0x1A	***dst*** 0xF8	***lhs*** 0x01	***rhs*** 0x01	***operandTypes*** 0xFEFE

Linked Instruction

8 bytes	8 bytes	8 bytes	8 bytes	8 bytes
op_add 0x00000000010003240	***dst*** 0xFFFFFFFFFFFFFFF8	***lhs*** 0x0000000000000001	***rhs*** 0x0000000000000001	***arithProfile*** 0x00000000100039D8

Execution

- Direct threading
- Inline caching

Execution

- offlineasm overview
- Direct threading
- Inline caching

Execution

- offlineasm overview
- Direct threading
- Inline caching

offlineasm

```
macro load(tmp, getter)
    getter(tmp)
    loadi [tmp], tmp
end

_label:
    load(t0, macro(tmp) move 42, tmp end)
```

offlineasm

```
macro load(tmp, getter)
    getter(tmp)
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    load(t0, macro(tmp) move 42, tmp end)
```

Temporary registers: t0-t5

offlineasm

```
macro load(tmp, getter)
    getter(tmp)
    loadi [tmp], tmp
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_label:
    load(t0, macro(tmp) move 42, tmp end)
```

Instruction suffixes

- b for byte
- h for 16-bit
- i for 32-bit
- q for 64-bit
- p for pointer

offlineasm

```
macro load(tmp, getter)
    getter(tmp)
    loadi [tmp], tmp
end

_label:
    load(t0, macro(tmp) move 42, tmp end)
```

Macros are lambda expressions that take zero or more arguments and return code

offlineasm

```
macro load(tmp, getter)
    getter(tmp)
    loadi [tmp], tmp
end

_label:
    load(t0, macro(tmp) move 42, tmp end)
```

Macros may be anonymous

offlineasm

```
macro load(tmp, getter)
    getter(tmp)
    loadi [tmp], tmp
end

_label:
    load(t0, macro(tmp) move 42, tmp end)
```

And macros can also be passed as arguments to other macros

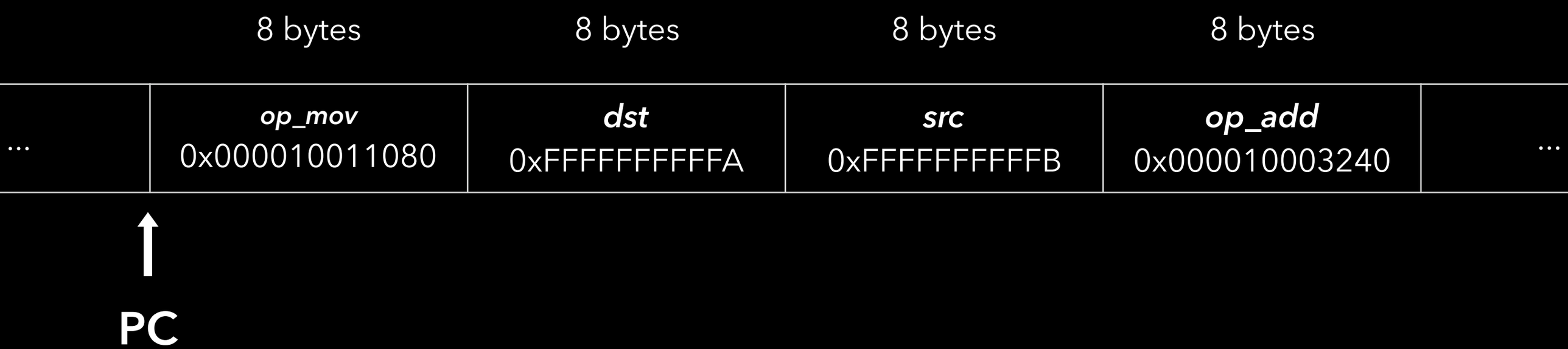
Execution

- offlineasm overview
- Direct threading
- Inline caching

Direct Threading

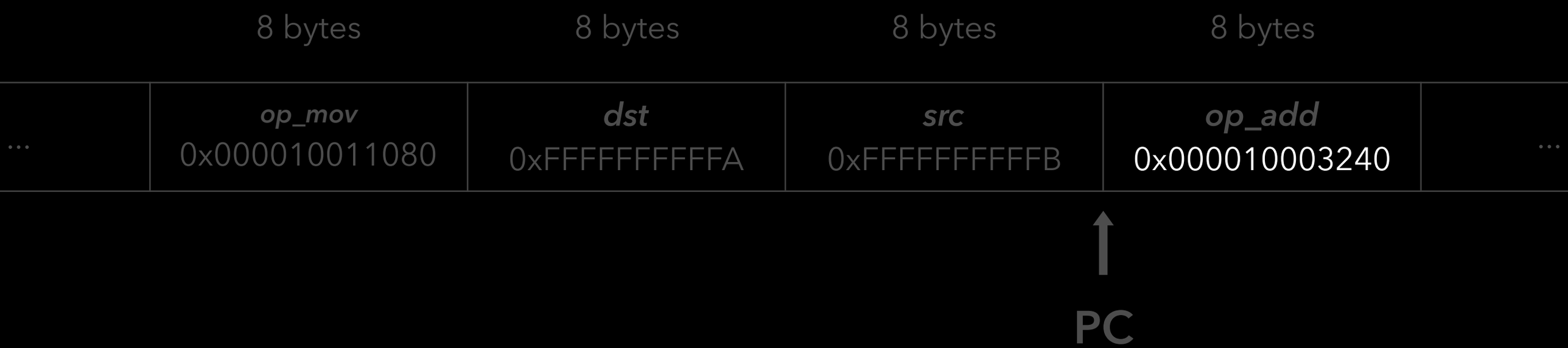

```
macro dispatch(instructionSize)
    addp instructionSize * PtrSize, PC
    jmp [PC]
end
```

Direct Threading




```
macro dispatch(instructionSize)
    addp instructionSize * PtrSize, PC
    jmp [PC]
end
```

Direct Threading




```
macro dispatch(instructionSize)
    addp instructionSize * PtrSize, PC
    jmp [PC]
end
```

Execution

- offlineasm overview
- Direct threading
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Inline Caching

```
object.field
```

↓

```
get_by_id object, field
```

Inline Caching

Structure #0x197	
field	0x10
x	0x20
Y	0x30

object #1	
0x10	42
0x20	“foo”
0x30	false

object #2	
0x10	[13, 42]
0x20	true
0x30	{}

Inline Caching

```
object.field
```

↓

```
get_by_id object, field, 0, 0
```

Structure ID

Offset

object #1	
0x10	42
0x20	"foo"
0x30	false

Structure #0x197	
field	0x10
x	0x20
Y	0x30

```
object.field
```

↓

```
get_by_id object, field, 0, 0
```

object #1	
0x10	42
0x20	"foo"
0x30	false

Structure #0x197	
field	0x10
x	0x20
Y	0x30

```
object.field
```

↓

```
get_by_id object, field, 0x197, 0x10
```

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- New bytecode format
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New Bytecode

- Compact
  - No separate linked format
  - Multiple encoding sizes
- Cacheable
  - No runtime values
  - Read-only instruction stream

Narrow Instructions

1 byte	1 byte	1 byte	1 byte	1 byte	1 byte
op_add 0x1A	***dst*** 0xF8	***lhs*** 0x01	***rhs*** 0x01	***operandTypes*** 0xFE	***metadataID*** 0x00

Wide Instructions

(32-bit words)

1 byte	4 bytes	4 bytes	4 bytes	4 bytes	4 bytes	4 bytes
op_wide 0x01	***op_add*** 0x0000001A	***dst*** 0xFFFFFFF8	***lhs*** 0x00000001	***rhs*** 0x00000001	***operandTypes*** 0xFFFFFFFE	***metadataID*** 0x00010000

Metadata Table

op_add
op_call
…

	0	1	…
arithProfile:	ArithProfile()	ArithProfile()	…

	0	1	…
arithProfile:	ArithProfile()	ArithProfile()	…
valueProfile:	ValueProfile()	ValueProfile()	…

Metadata Table

~200 opcodes × 8 bytes × ~23k tables

=

~36MB

Metadata Table

Header			Payload			
0x0	*0x4*	…	*0x100*	*0x110*	*0x120*	…
op_add 0x100	***op_call*** 0x120	…	OpAdd::Metadata[0]	OpAdd::Metadata[1]	OpCall::Metadata[0]	…

- Allocate the whole table as a single chunk of memory
- Only allocate space for opcodes that have metadata
- Change the header from pointer to unsigned offset

Execution

- Indirect threading
- Inline caching
- Wide instruction execution

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- Wide instruction execution

Indirect Threading

```
macro dispatch(instructionSize)
    addp instructionSize * PtrSize, PC
    jmp [PC]
end
```

Indirect Threading

```
macro dispatch(instructionSize)
    addp instructionSize, PC
    loadb [PC], t0
    leap _g_opcodeMap, t1
    jmp [t1, t0, PtrSize]
end
```

Execution

- Indirect threading
- Inline caching
- Wide instruction execution

Inline Caching

CallFrame

↓

CodeBlock

↓

Instruction Stream

↓

MetadataTable **[** *OpcodeID* **] [** MetadataID **]**

Execution

- Indirect threading
- Inline caching
- Wide instruction execution

Wide Instruction Execution

```
macro dispatch(instructionSize)
    addp instructionSize, PC
    loadb [PC], t0
    leap _g_opcodeMap, t1
    jmp [t1, t0, PtrSize]
end
```

Wide Instruction Execution

```
macro dispatch(instructionSize)
    addp instructionSize, PC
    loadb [PC], t0
    leap _g_opcodeMap, t1
    jmp [t1, t0, PtrSize]
end

_llint_op_wide:
    loadi 1[PC], t0
    leap _g_opcodeMapWide, t1
    jmp [t1, t0, PtrSize]
```

Wide Instruction Execution

```
macro dispatch(instructionSize)
    addp instructionSize, PC
    loadb [PC], t0
    leap _g_opcodeMap, t1
    jmp [t1, t0, PtrSize]
end

_llint_op_wide:
    loadi 1[PC], t0
    leap _g_opcodeMapWide, t1
    jmp [t1, t0, PtrSize]
```

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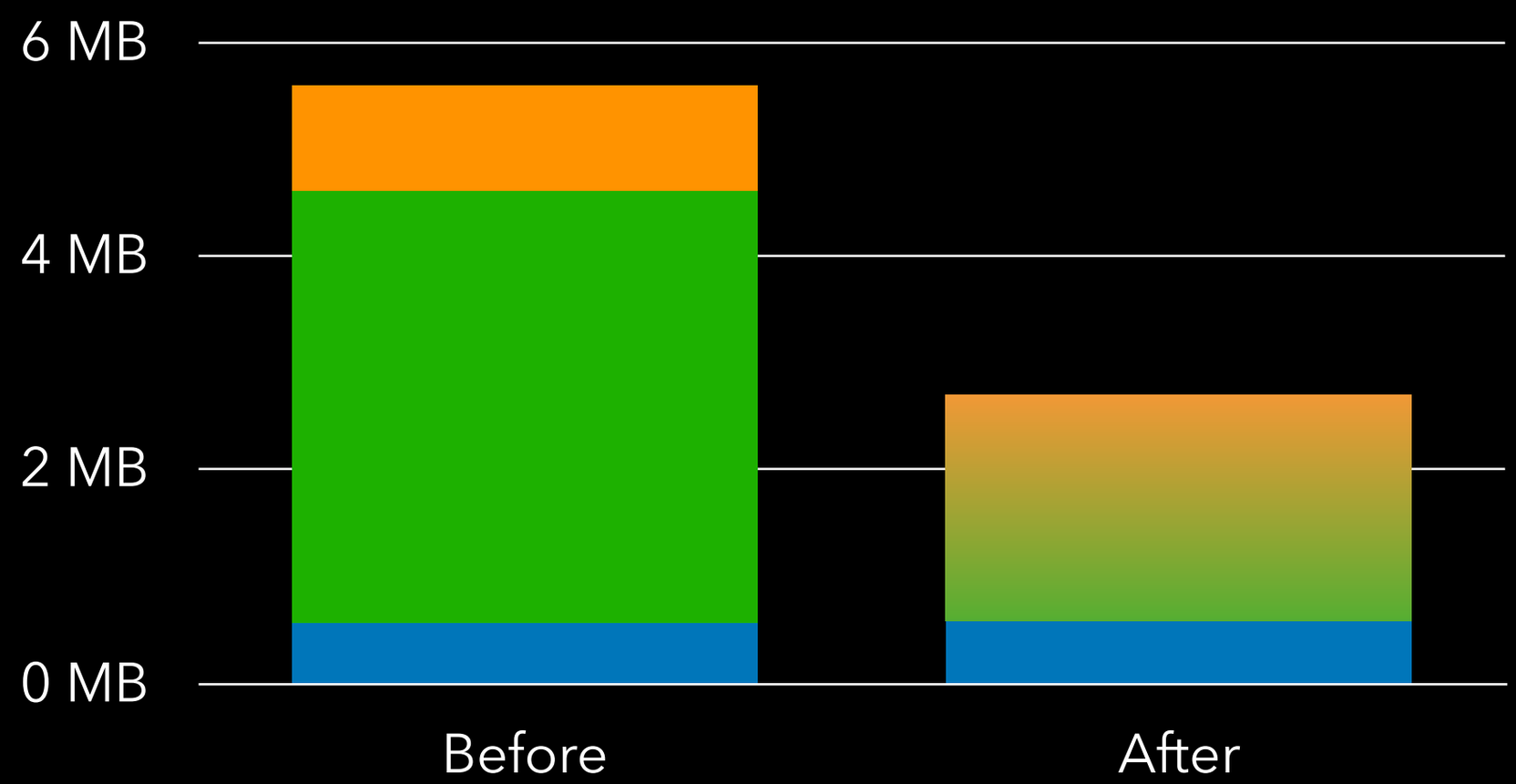

Description	Before	After	%
Unlinked	0.55 MB	0.57 MB	+4%
Linked	4.05 MB	2.14 MB	-57%
Metadata	0.99 MB		
Total	***5.60 MB***	***2.71 MB***	***-52%***

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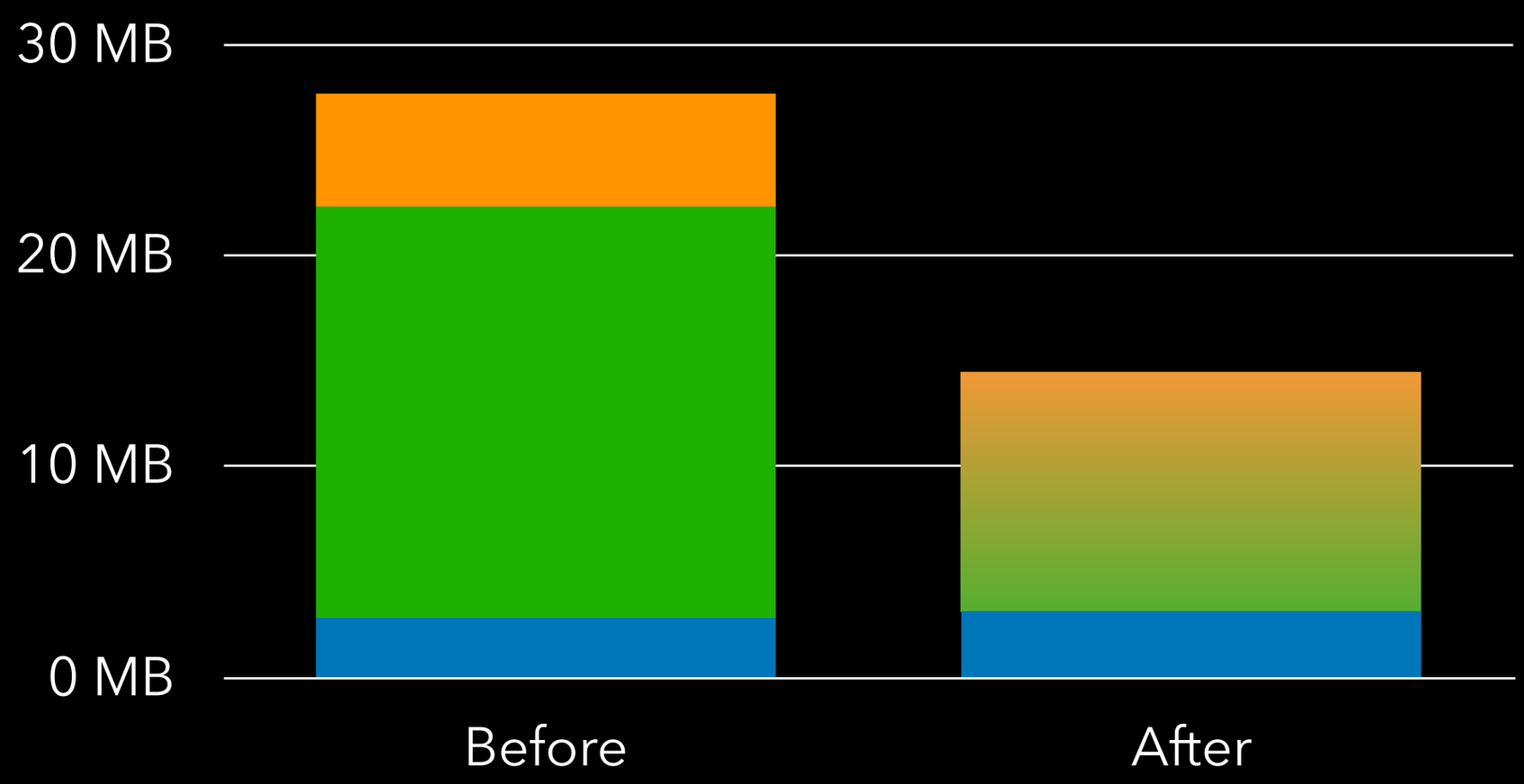

Description	Before	After	%
Unlinked	2.76 MB	3.08 MB	+12%
Linked	19.51 MB	11.37 MB	-54%
Metadata	5.34 MB		
Total	***27.61 MB***	***14.45 MB***	***-48%***

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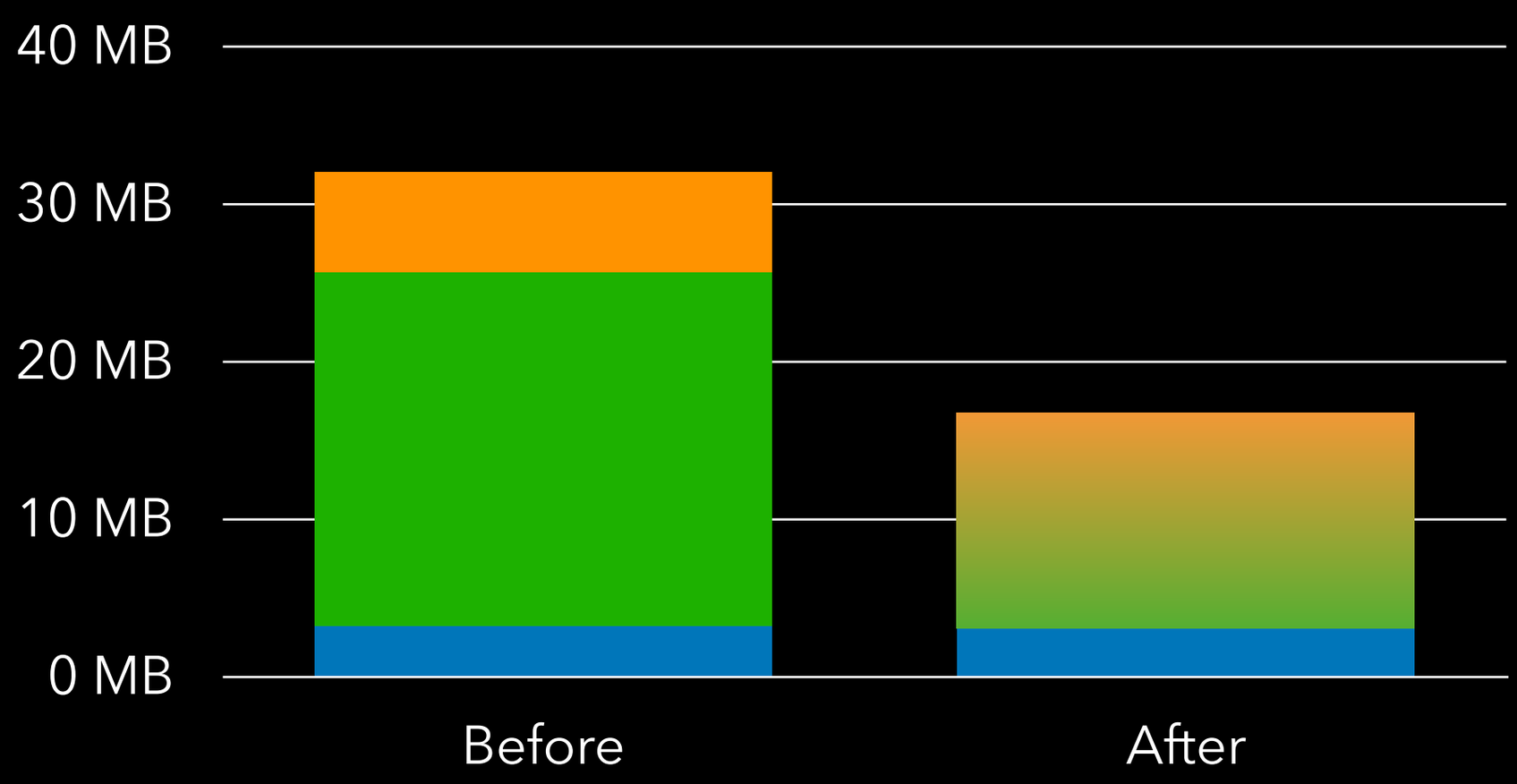

Description	Before	After	%
Unlinked	3.11 MB	2.99 MB	-4%
Linked	22.43 MB	13.66 MB	-52%
Metadata	6.51 MB		
Total	***32.04 MB***	***16.65 MB***	***-48%***

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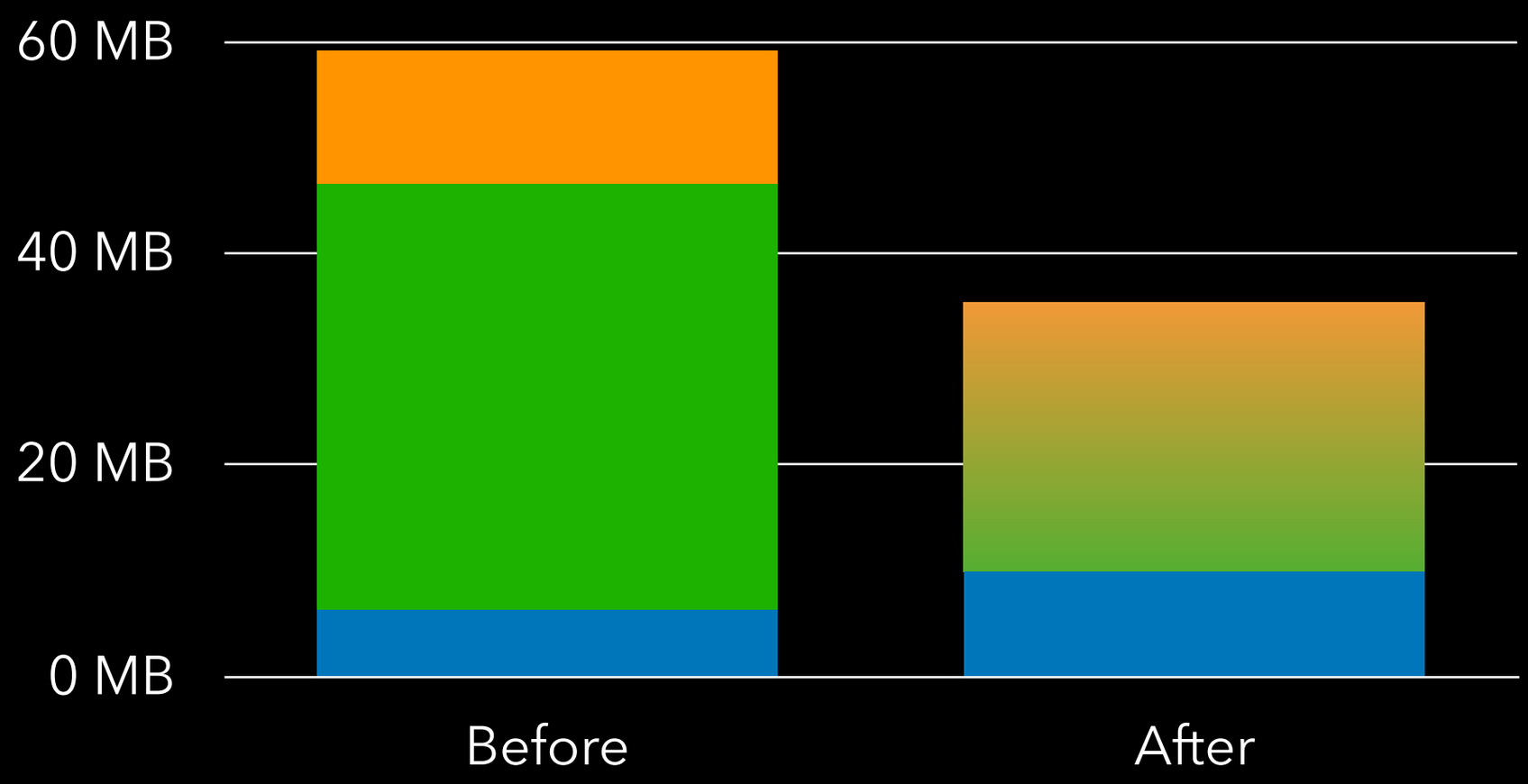

Description	Before	After	%
Unlinked	6.17 MB	9.89 MB	+60%
Linked	40.28 MB	25.51 MB	-52%
Metadata	12.75 MB		
Total	***59.21 MB***	***35.40 MB***	***-40%***

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- More than 12k code blocks
- More than 830k instructions
- 270k wide instructions (33%)

Wide Instructions

(16-bit words)

1 byte	2 bytes	2 bytes	2 bytes	2 bytes	2 bytes	2 bytes
op_wide16 0x00	***op_add*** 0x001A	***dst*** 0xFFF8	***lhs*** 0x0001	***rhs*** 0x0001	***operandTypes*** 0xFEFE	***metadataID*** 0x0100

Metadata Table

Header			Payload			
0x0	*0x2*	…	*0x80*	*0x90*	*0xA0*	…
op_add 0x80	***op_call*** 0xA0	…	OpAdd::Metadata[0]	OpAdd::Metadata[1]	OpCall::Metadata[0]	…

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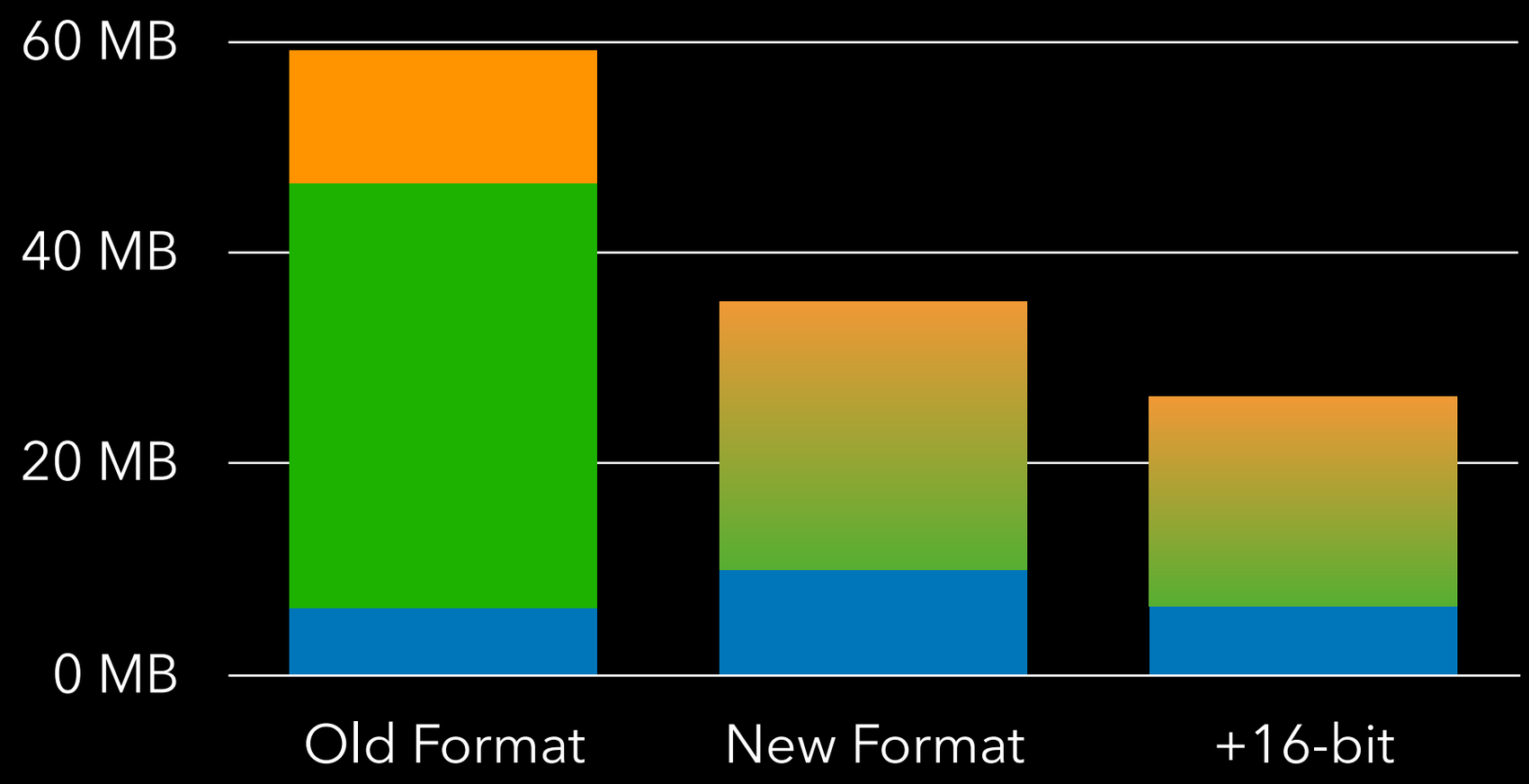

Description	Old Format	New Format	+ 16-bit
Unlinked	6.17 MB	9.89 MB	6.40 MB
Linked	40.28 MB	25.51 MB	20.03 MB
Metadata	12.75 MB		
Total	***59.21 MB***	***35.40 MB***	***26.42 MB***

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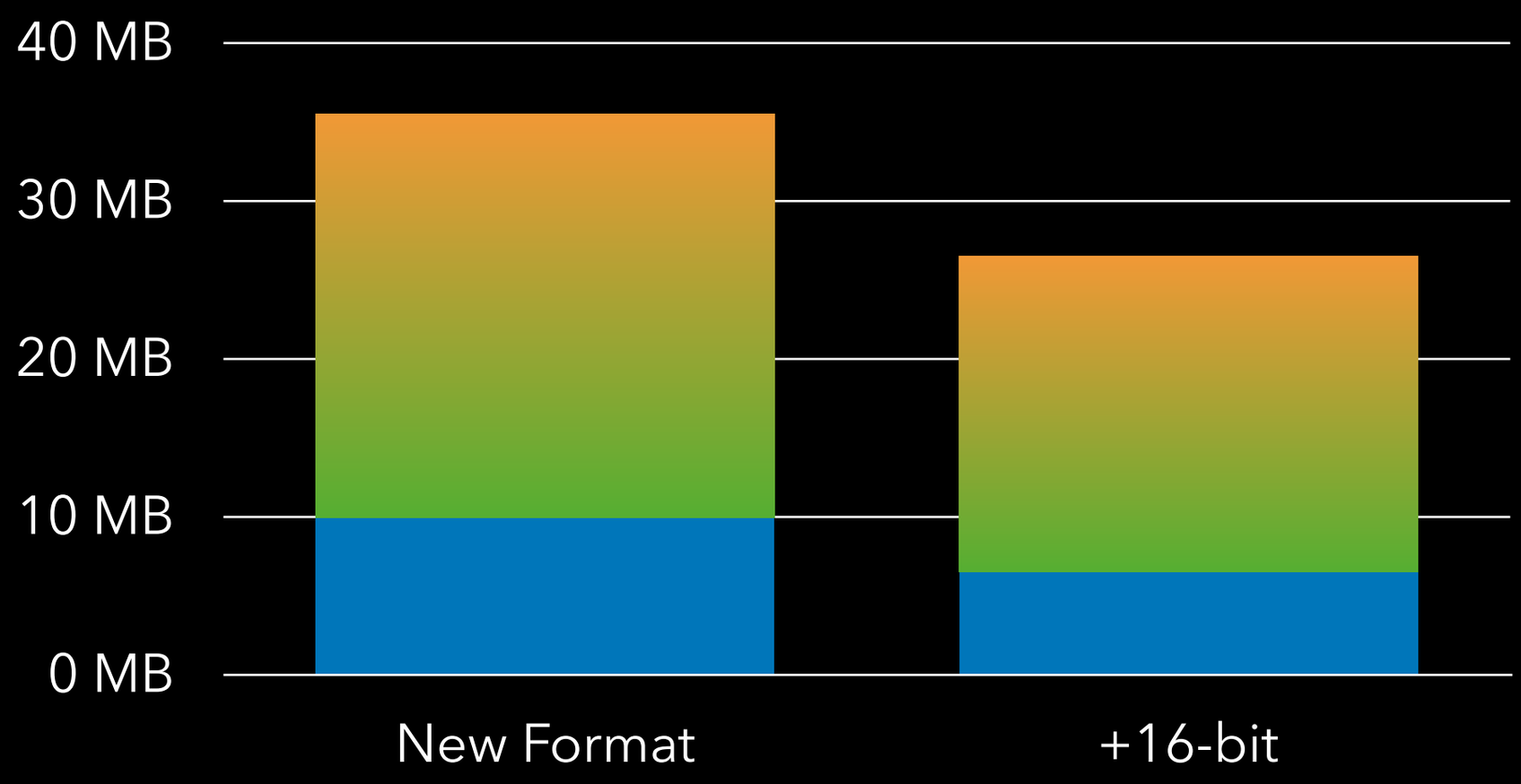

Description	New Format	+ 16-bit	%
Unlinked	9.89 MB	6.40 MB	-35%
Linked	25.51 MB	20.03 MB	-21%
Metadata			
Total	***35.40 MB***	***26.42 MB***	***-26%***

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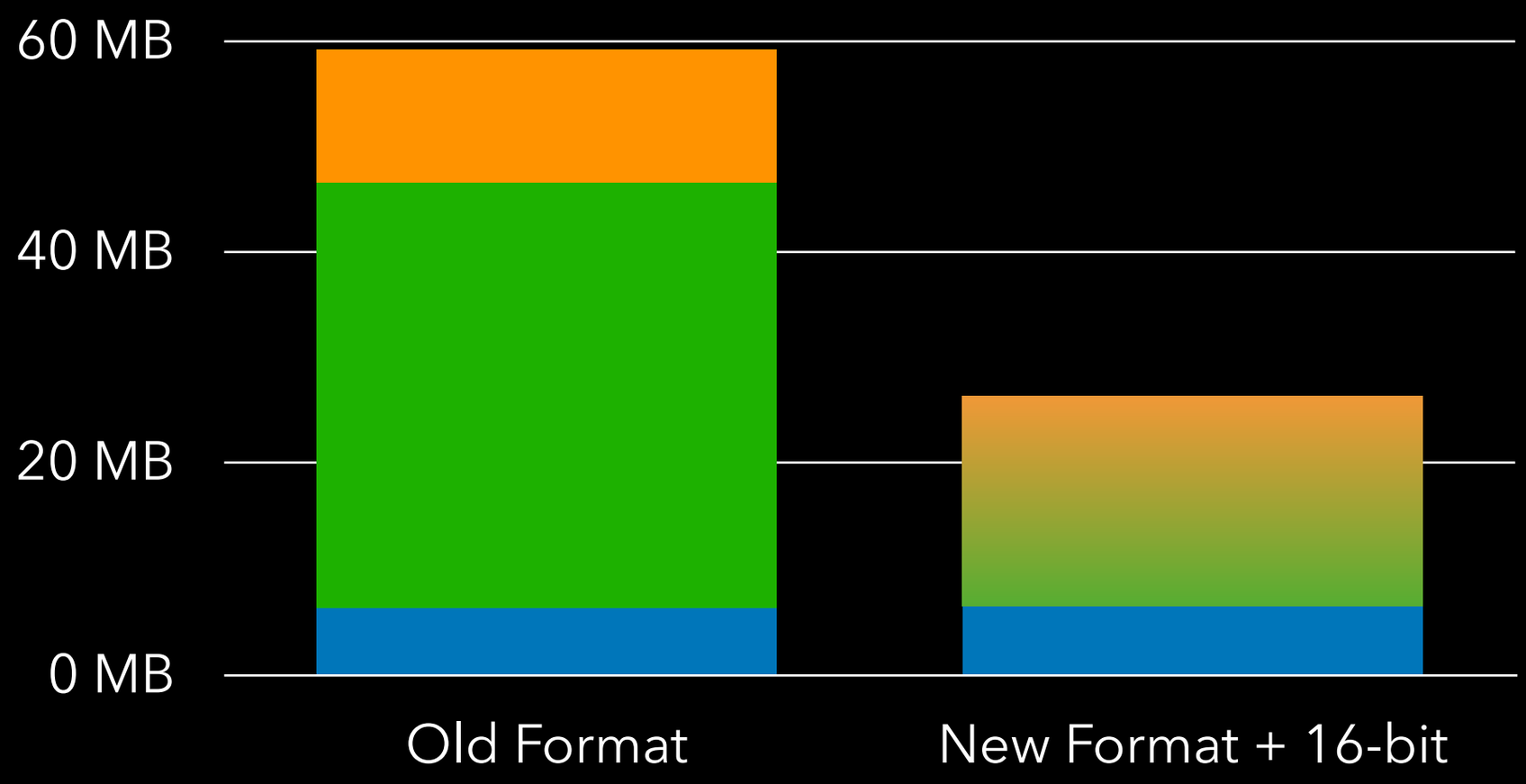

Description	Before	16-bit	%
Unlinked	6.17 MB	6.40 MB	+4%
Linked	40.28 MB	20.03 MB	-62%
Metadata	12.75 MB		
Total	***59.21 MB***	***26.42 MB***	***-55%***

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Old Instruction Definition

```
{ "name": "op_add", "length": 5 }
```

Old Instruction Access

```
SLOW_PATH_DECL(slow_path_add)
{
    JSValue lhs = OP_C(2).jsValue();
    JSValue rhs = OP_C(3).jsValue();
    ...
}
```

Old Instruction Access

```
SLOW_PATH_DECL(slow_path_add)
{
    JSValue lhs = exec->r(pc[2].u.operand).jsValue();
    JSValue rhs = exec->r(pc[3].u.operand).jsValue();
    …
}
```

Old Instruction Access

```
SLOW_PATH_DECL(slow_path_add)
{
    JSValue lhs = exec->r(pc[2].u.operand).jsValue();
    JSValue rhs = exec->r(pc[3].u.operand).jsValue();
    …
}
```

Old Instruction Access

```
union {
    void* pointer;
    Opcode opcode;
    int operand;
    unsigned unsignedValue;
    WriteBarrierBase<Structure> structure;
    StructureID structureID;
    WriteBarrierBase<SymbolTable> symbolTable;
    WriteBarrierBase<StructureChain> structureChain;
    WriteBarrierBase<JSCell> jsCell;
    WriteBarrier<Unknown>* variablePointer;
    Special::Pointer specialPointer;
    PropertySlot::GetValueFunc getterFunc;
    LLIntCallLinkInfo* callLinkInfo;
    UniquedStringImpl* uid;
```

New Instruction Definition

```
op :add,
    args: {
        dst: VirtualRegister,
        lhs: VirtualRegister,
        rhs: VirtualRegister,
        operandTypes: OperandTypes,
    },
    metadata: {
        arithProfile: ArithProfile,
    }
```

Opcode Struct

```
struct OpAdd : public Instruction {
    static constexpr OpcodeID opcodeID = op_add;

    VirtualRegister m_dst;
    VirtualRegister m_lhs;
    VirtualRegister m_rhs;
    OperandTypes m_operandTypes;
    unsigned m_metadataID;
};
```

Metadata Struct

```
struct OpAdd::Metadata {
    WTF_MAKE_NONCOPYABLE(Metadata);

public:
    Metadata(const OpAdd& __op)
        : m_arithProfile(__op.m_operandTypes)
    { }

    ArithProfile m_arithProfile;
};
```

Autogenerate all the things!

- Instruction fitting
- Instruction decoding (narrow vs wide)
- Pretty printing
- Constants for offlineasm
- Opcode IDs
- ...

New Instruction Access

```
SLOW_PATH_DECL(slow_path_add)
{
    OpAdd bytecode = pc->as<OpAdd>();
    JSValue lhs = GET_C(bytecode.m_lhs);
    JSValue rhs = GET_C(bytecode.m_rhs);
    ...
}
```

New Instruction Access

```
SLOW_PATH_DECL(slow_path_add)
{
    OpAdd bytecode = pc->as<OpAdd>();
    JSValue lhs = exec->r(bytecode.m_lhs.offset());
    JSValue rhs = exec->r(bytecode.m_rhs.offset());
    ...
}
```

New Instruction Access

```
SLOW_PATH_DECL(slow_path_add)
{
    OpAdd bytecode = pc->as<OpAdd>();
    JSValue lhs = exec->r(bytecode.m_lhs.offset());
    JSValue rhs = exec->r(bytecode.m_rhs.offset());
    ...
}
```

Thank you!

@tadeuzagallo