The VMKit project: Java and .Net on top of LLVM

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What is VMKit?

- Glue between existing VM components
- A drop-in replacement to Java and .Net
- Usage:
  - vmkit -java HelloWorld
  - vmkit -net HelloWorld.exe

Scientific Goals

- Build VMs with existing components
  - JIT, GC, class libraries, threads
- VM Interoperability
  - Execution in the same address space
  - Isolation
  - VM communications

This talk:

Trying to bring back the VM in LL VM

1. The design of VMKit
2. VMKit's performance
3. LL: “VM where are you?”

The design of VMKit

VMKit

Glue between existing VM components

- JIT: LLVM
- GC: Boehm, Mmap2
- Libraries: Classpath, Mono, Pnetlib
- Threads: Posix threads
- Exception handling: GCC

VMKit runtime

- Internal representation of classes (assemblies)
- Convert bytecode (ILASM) to LLVM IR
- Method (field) lookup
- VM runtime
  - Threads, reflection, exceptions

Execution overview (java, .net)

- Load .class and .jar (.exe)
- JIT main()
  - Insert stubs for methods (lazy compilation) and fields
- Run main()
  - Stubs call JIT
  - Load class (assembly) dynamically

JIT Interface

- Compile-only approach
- Custom memory manager
  - Stack unwinding
- Custom module (function) provider
  - Constant pool (Assembly) lookup

From bytecode to LLVM IR

- All JVM bytecode (MSIL) is expressible in LLVM
  - One-to-one translations (e.g. add, sub, div, local loads and stores, static calls ...)
  - One-to-many translations (e.g. array stores, virtual calls, field loads and store ...)
  - Runtime calls (e.g. exceptions, inheritance, synchronizations)
- Type resolution in .Net
  - LLVM Opaque types (for recursive types)

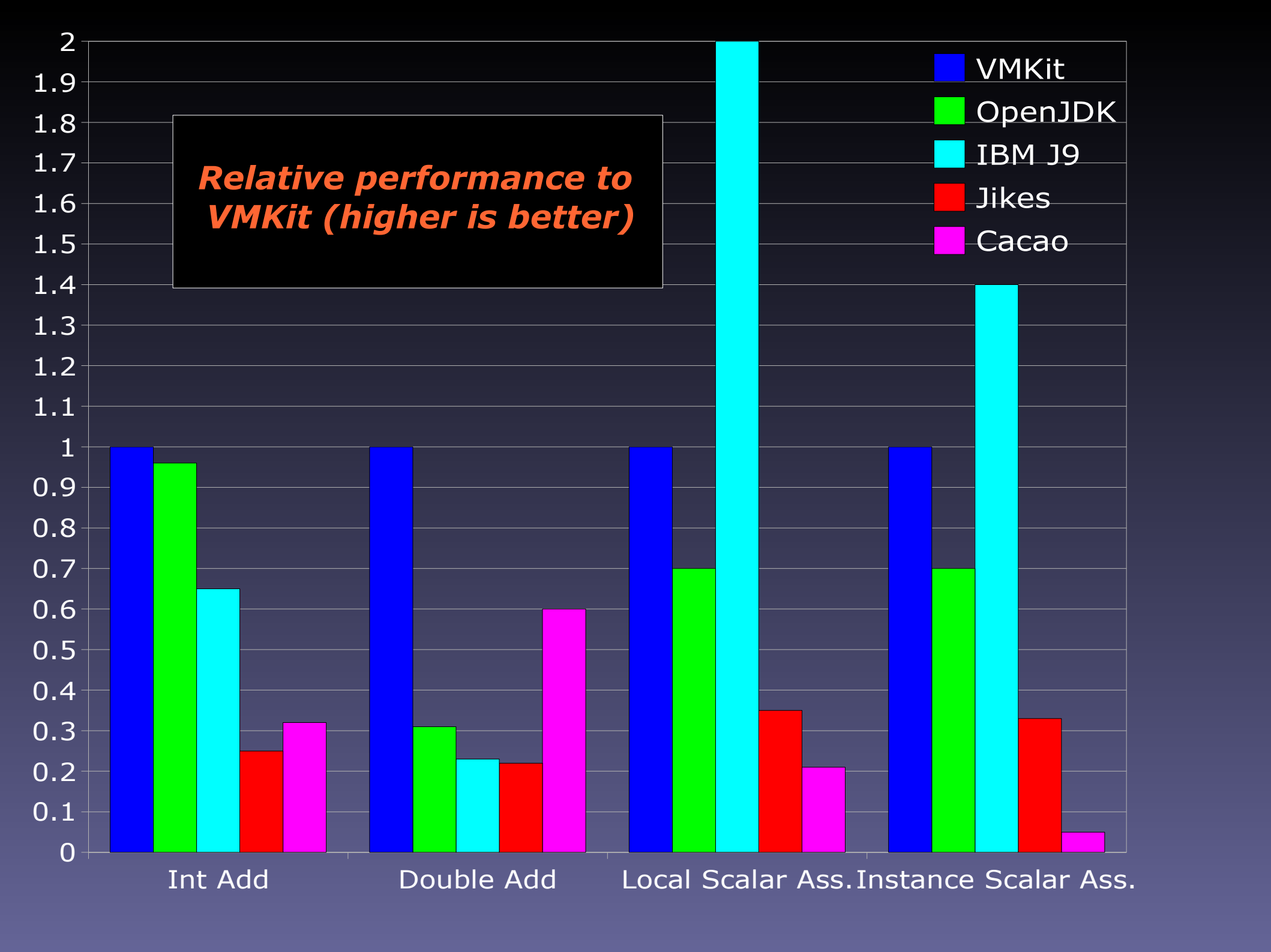
Useful LLVM optimizations

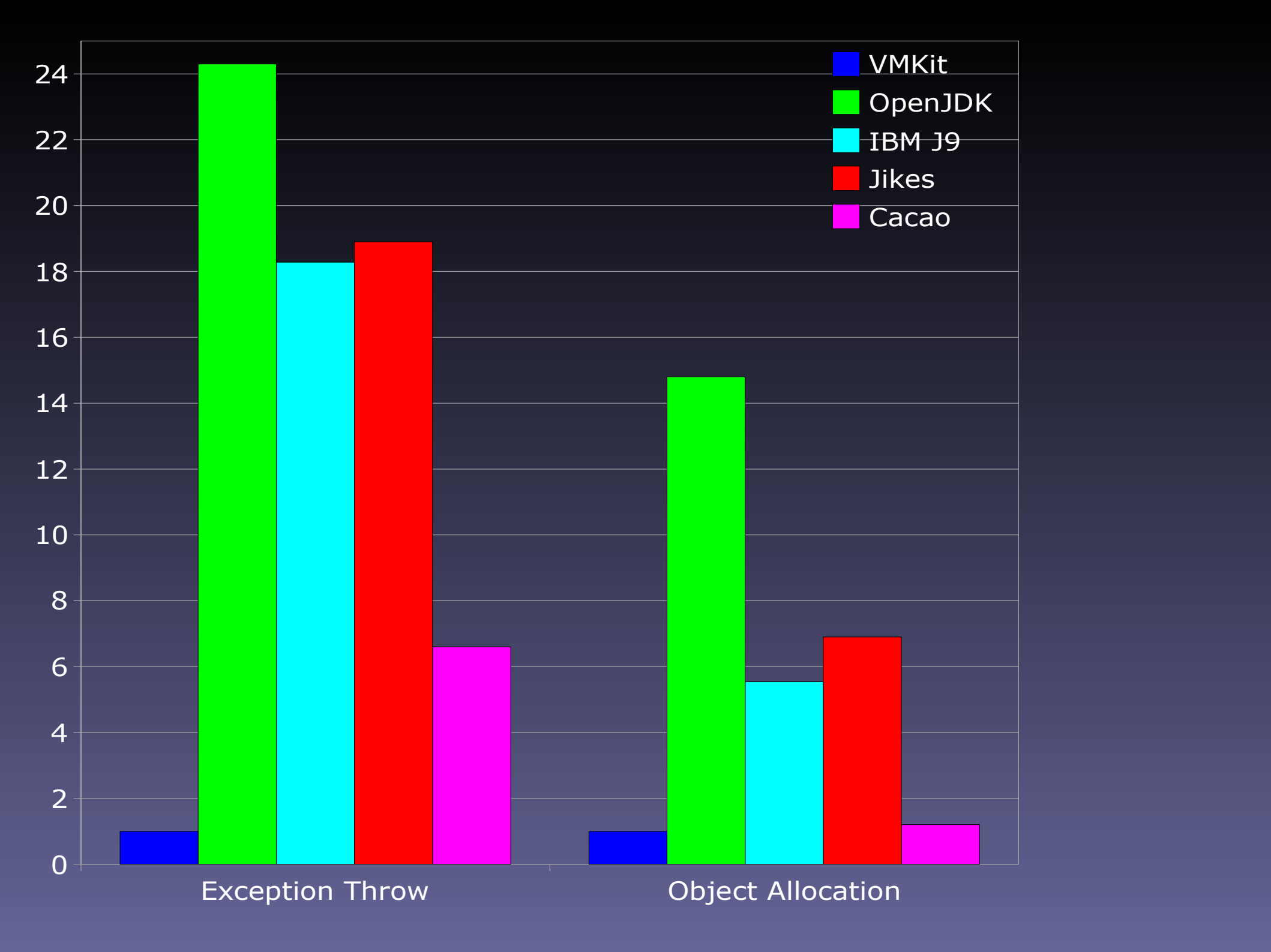
- Mem2reg
  - Move local variables to registers
- Global Value Numbering
  - Load constant values only once
- Predicate Simplifier
  - Removal of array bounds checks
- Loop Invariant Code Motion
  - Load constant values out of the loop

Performance

JVM Benchmarks

- Athlon XP 1800+, 512M, Linux
- 4 JVMs
  - OpenJDK, IBM J9, Jikes RVM, Cacao
- Java Grande Forum Benchmark
  - Section1: low-level operations
  - Section2: scientific benchmarks
- SPEC JVM98
  - Real-world applications


Relative performance to VMKit (higher is better)
VMKit
OpenJDK
IBM J9
Jikes
Cacao
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Int Add
Double Add
Local Scalar Ass.
Instance Scalar Ass.


VMKit
OpenJDK
IBM J9
Jikes
Cacao
24
22
20
18
16
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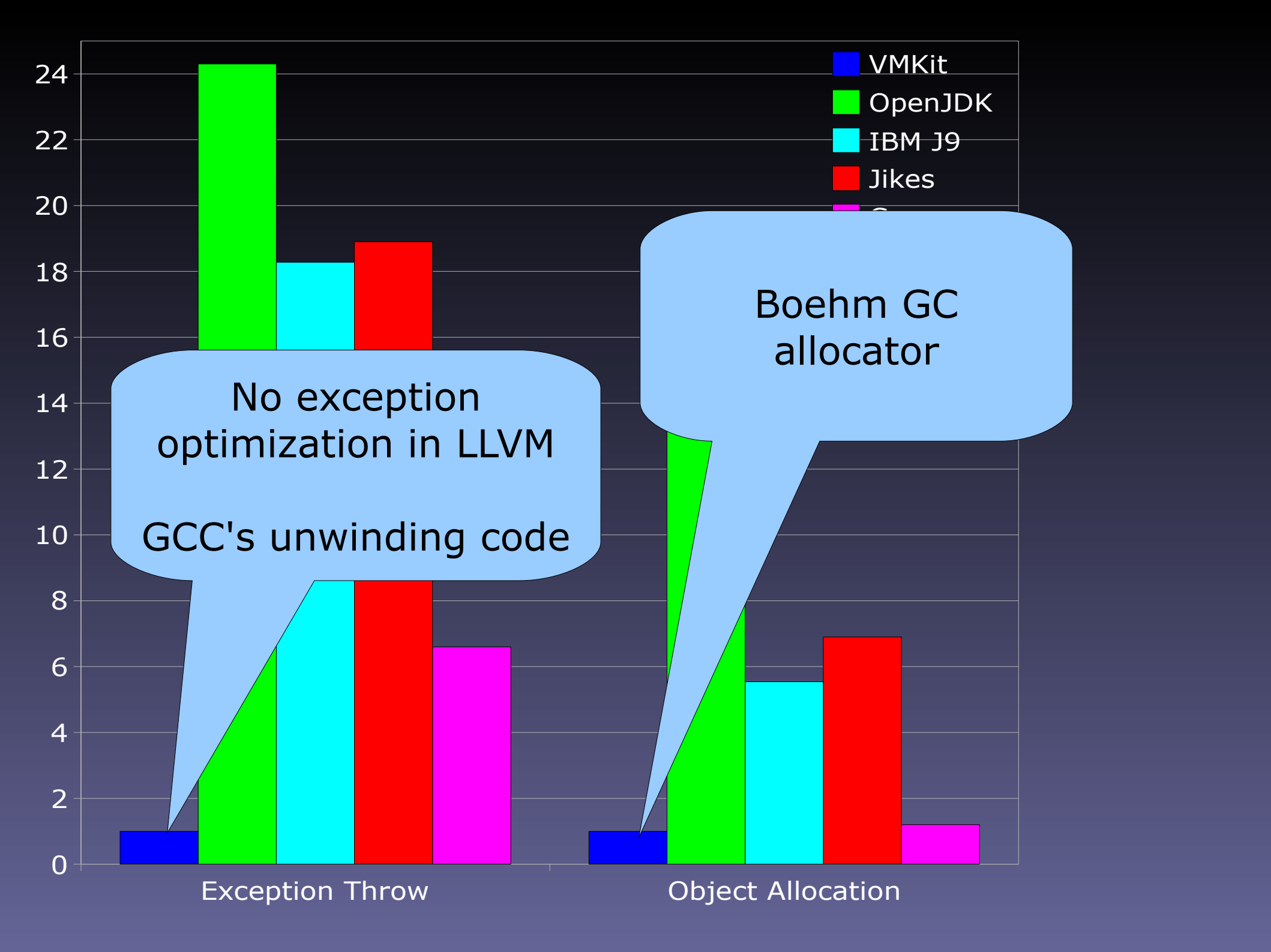
12
10
8
6
4
2
0
Exception Throw
Object Allocation


24
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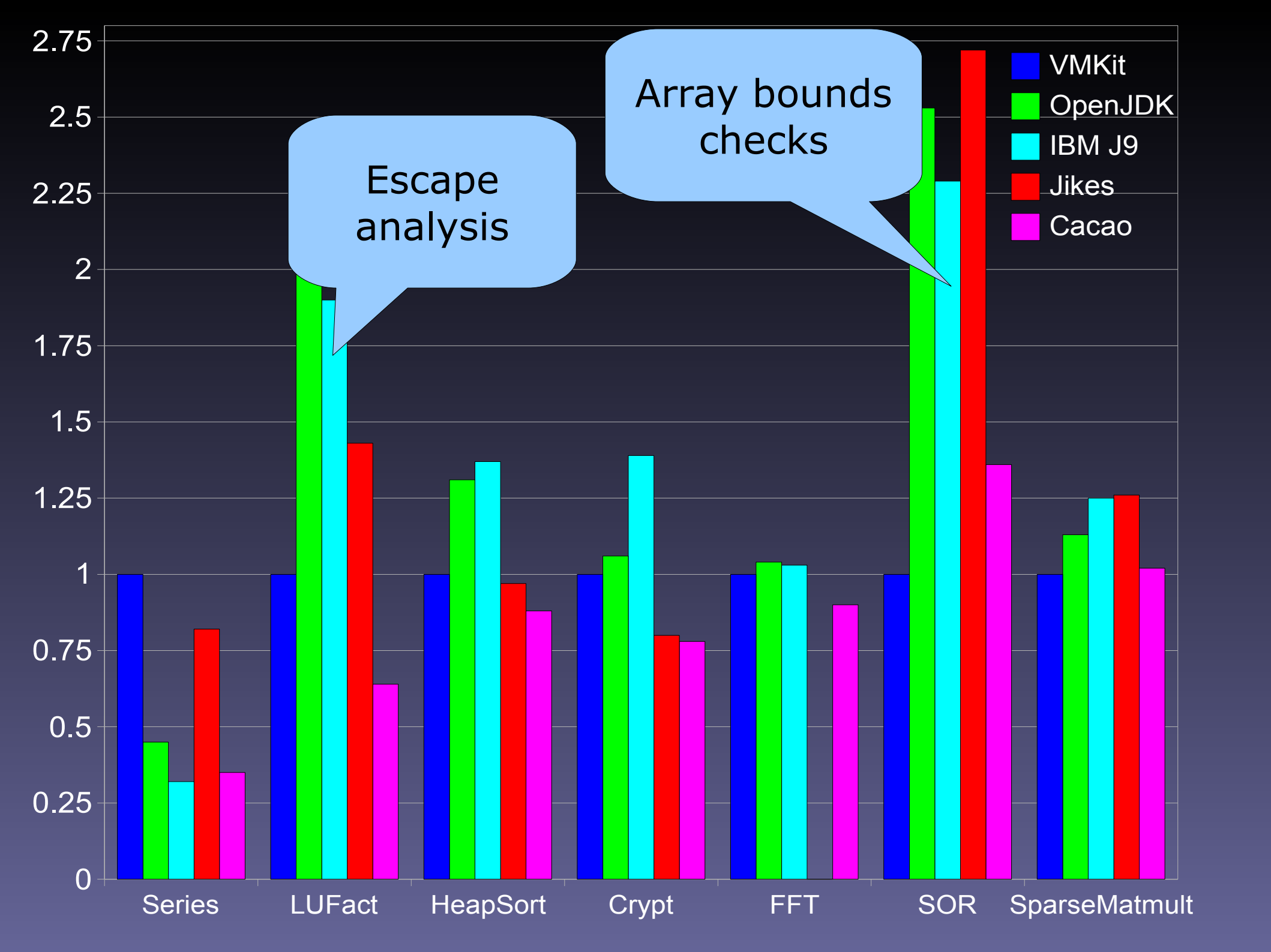
VMKit
OpenJDK
IBM J9
Jikes
No exception optimization in LLVM
GCC's unwinding code
Boehm GC allocator
Exception Throw
Object Allocation


2.75
2.5
2.25
2
1.75
1.5
1.25
1
0.75
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0.25
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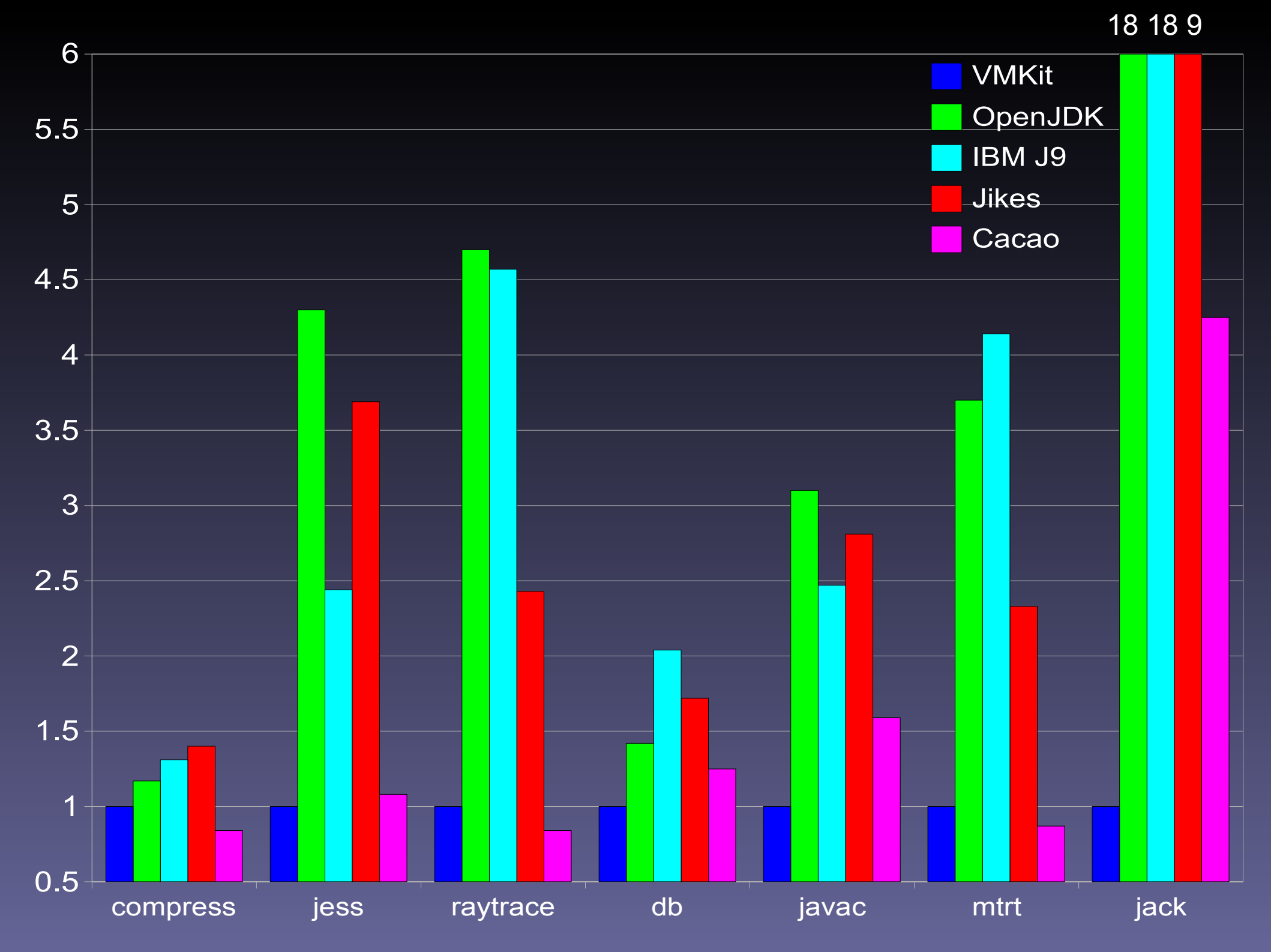
Escape analysis
Array bounds checks
VMKit
OpenJDK
IBM J9
Jikes
Cacao
Series
LUFact
HeapSort
Crypt
FFT
SOR
SparseMatmult


18 18 9
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5.5
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4.5
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3
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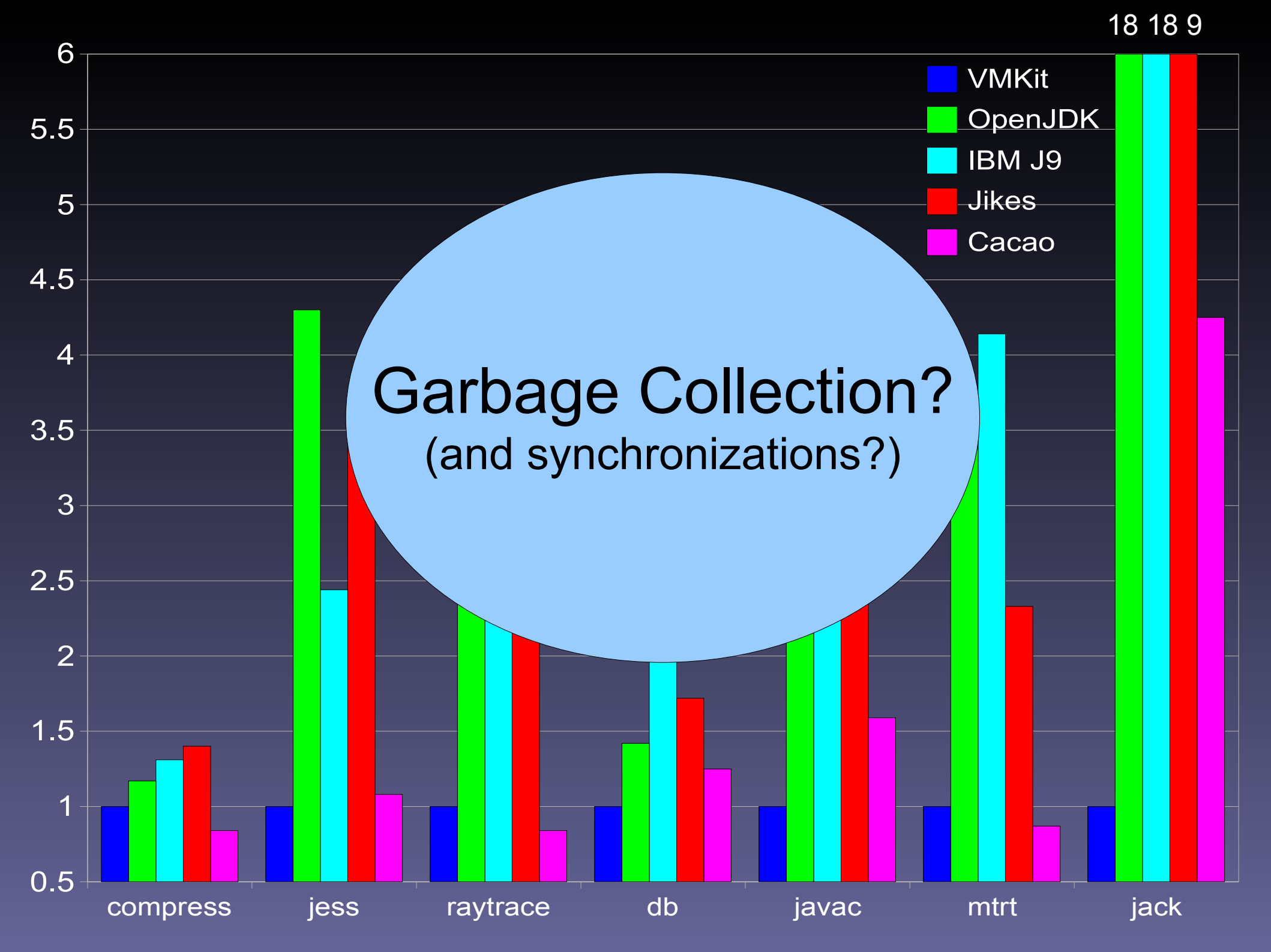
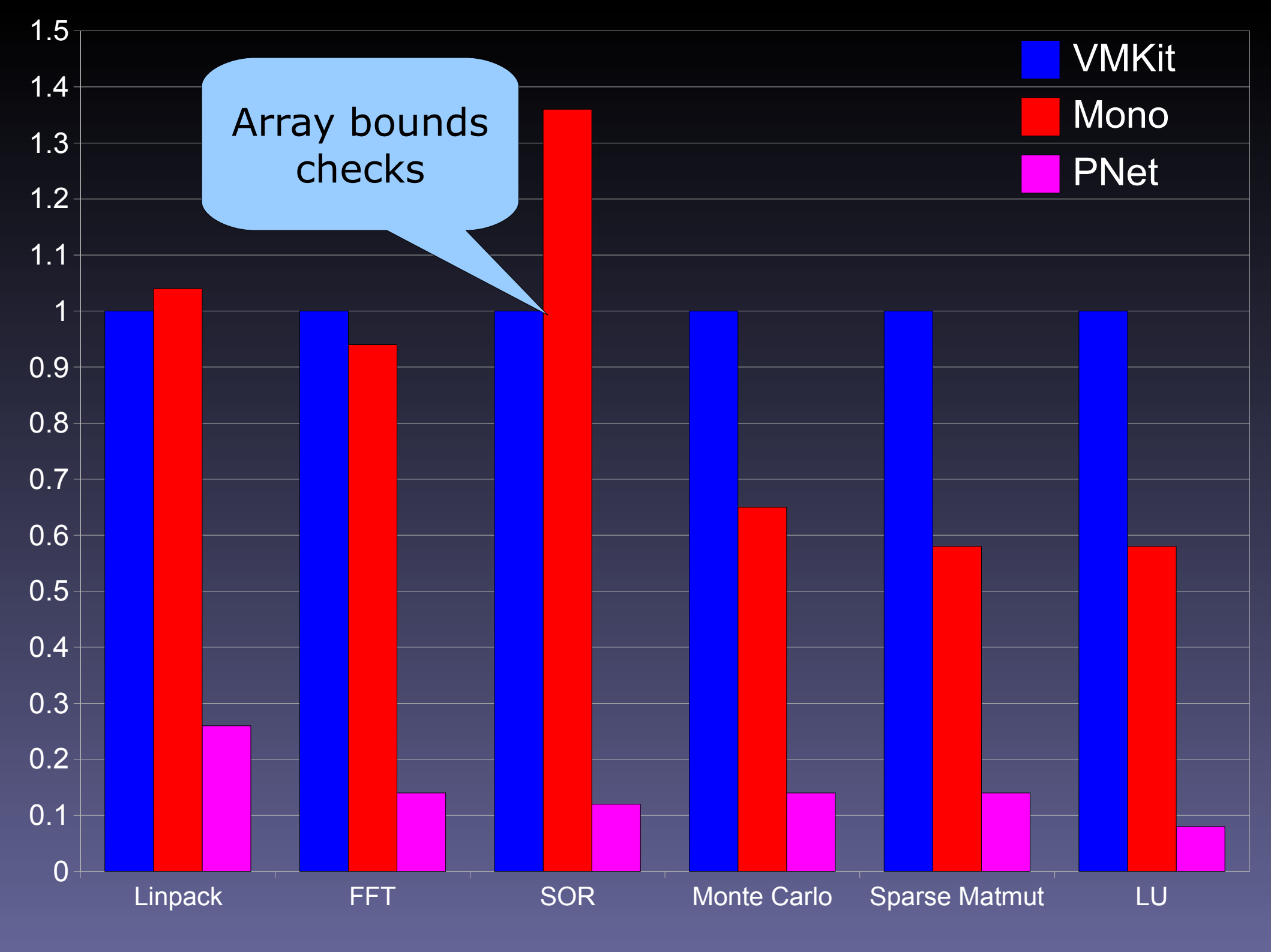
2
1.5
1
0.5
VMKit
OpenJDK
IBM J9
Jikes
Cacao
compress
jess
raytrace
db
javac
mtrt
jack


18 18 9
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
VMKit
OpenJDK
IBM J9
Jikes
Cacao
Garbage Collection?
(and synchronizations?)
compress
jess
raytrace
db
javac
mtrt
jack

.Net Benchmarks

- Athlon XP 1800+, 512M, Linux
- 2 .Net
  - Mono, Pnet
- No comparison with Microsoft
- PNetMark
  - Scientific applications


1.5
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1.2
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0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Array bounds checks
VMKit
Mono
PNet
Linpack
FFT
SOR
Monte Carlo
Sparse Matmut
LU

Losing the VM in LL VM

Compilation time

- VMKit uses a compilation-only approach
  - No mixed-mode in LLVM
  - No dynamic optimizations in LLVM

How does that affect application startup?

Tomcat startup (OpenJDK)

Jul 31, 2008 7:17:39 PM org.apache.coyote.http11.Http11Protocol init
INFO: Initializing Coyote HTTP/1.1 on http-8080
Jul 31, 2008 7:17:39 PM org.apache.catalina.startup.Catalina load
INFO: Initialization processed in 1367 ms
Jul 31, 2008 7:17:40 PM org.apache.catalina.core.StandardService start
INFO: Starting service Catalina
Jul 31, 2008 7:17:40 PM org.apache.catalina.core.StandardEngine start
INFO: Starting Servlet Engine: Apache Tomcat/6.0.16
Jul 31, 2008 7:17:40 PM org.apache.coyote.http11.Http11Protocol start
INFO: Starting Coyote HTTP/1.1 on http-8080
Jul 31, 2008 7:17:40 PM org.apache.jk.common.ChannelSocket init
INFO: JK: ajp13 listening on /0.0.0.0:8009
Jul 31, 2008 7:17:40 PM org.apache.jk.server.JkMain start
INFO: Jk running ID=0 time=0/44 config=null
Jul 31, 2008 7:17:40 PM org.apache.catalina.startup.Catalina start
INFO: Server startup in 1142 ms

Tomcat startup (VMKit w/ Opt)

Jul 31, 2008 6:35:51 PM org.apache.coyote.http11.Http11Protocol init
INFO: Initializing Coyote HTTP/1.1 on http-8080
Jul 31, 2008 6:35:51 PM org.apache.catalina.startup.Catalina load
INFO: Initialization processed in 15020 ms
Jul 31, 2008 6:35:54 PM org.apache.catalina.core.StandardService start
INFO: Starting service Catalina
Jul 31, 2008 6:35:54 PM org.apache.catalina.core.StandardEngine start
INFO: Starting Servlet Engine: Apache Tomcat/6.0.16
Jul 31, 2008 6:36:11 PM org.apache.coyote.http11.Http11Protocol start
INFO: Starting Coyote HTTP/1.1 on http-8080
Jul 31, 2008 6:36:13 PM org.apache.jk.common.ChannelSocket init
INFO: JK: ajp13 listening on /0.0.0.0:8009
Jul 31, 2008 6:36:13 PM org.apache.jk.server.JkMain start
INFO: Jk running ID=0 time=19/738 config=null
Jul 31, 2008 6:36:13 PM org.apache.catalina.startup.Catalina start
INFO: Server startup in 22660 ms

Tomcat startup (VMKit w/o Opt)

Jul 31, 2008 6:51:42 PM org.apache.coyote.http11.Http11Protocol init
INFO: Initializing Coyote HTTP/1.1 on http-8080
Jul 31, 2008 6:51:42 PM org.apache.catalina.startup.Catalina load
INFO: Initialization processed in 10219 ms
Jul 31, 2008 6:51:44 PM org.apache.catalina.core.StandardService start
INFO: Starting service Catalina
Jul 31, 2008 6:51:44 PM org.apache.catalina.core.StandardEngine start
INFO: Starting Servlet Engine: Apache Tomcat/6.0.16
Jul 31, 2008 6:51:57 PM org.apache.coyote.http11.Http11Protocol start
INFO: Starting Coyote HTTP/1.1 on http-8080
Jul 31, 2008 6:51:59 PM org.apache.jk.common.ChannelSocket init
INFO: JK: ajp13 listening on /0.0.0.0:8009
Jul 31, 2008 6:52:00 PM org.apache.jk.server.JkMain start
INFO: Jk running ID=0 time=16/679 config=null
Jul 31, 2008 6:52:00 PM org.apache.catalina.startup.Catalina start
INFO: Server startup in 17729 ms

VMKit: Compilation time w/ Opt

---User Time---	--System Time--	--User+System--	---Wall Time---	--- Name ---
1.2840 (8.0%)	17.5490 (52.8%)	18.8331 (38%)	19.6628 (39%)	X86 DAG->DAG Instruction Selection
3.2201 (20.2%)	0.7200 (2.1%)	3.9402 (8.0%)	4.2831 (8.5%)	Unswitch loops
3.3322 (20.9%)	0.7800 (2.3%)	4.1122 (8.3%)	4.1940 (8.3%)	Predicate Simplifier
1.1120 (7.0%)	0.8240 (2.4%)	1.9361 (3.9%)	1.9569 (3.8%)	Linear Scan Register Allocator
1.0640 (6.6%)	0.8800 (2.6%)	1.9441 (3.9%)	1.9235 (3.8%)	Live Variable Analysis
0.8200 (5.1%)	0.9280 (2.7%)	1.7481 (3.5%)	1.5910 (3.1%)	Live Interval Analysis
0.6920 (4.3%)	0.6760 (2.0%)	1.3680 (2.7%)	1.3666 (2.7%)	Global Value Numbering
0.6640 (4.1%)	0.5880 (1.7%)	1.2520 (2.5%)	1.2098 (2.4%)	Simple Register Coalescing
0.3480 (2.1%)	0.4520 (1.3%)	0.8000 (1.6%)	0.7449 (1.4%)	Combine redundant instructions
0.1640 (1.0%)	0.3400 (1.0%)	0.5040 (1.0%)	0.5229 (1.0%)	Combine redundant instructions
15.8850 (100.0%)	33.1980 (100.0%)	49.0830 (100.0%)	50.2414 (100.0%)	TOTAL

VMKit: Compilation time w/o Opt

---User Time---	--System Time--	--User+System--	---Wall Time---	--- Name ---
2.0081 (24.9%)	24.4535 (79.4%)	26.4616 (68%)	27.2189 (68%)	X86 DAG->DAG Instruction Selection
1.6041 (19.9%)	0.9960 (3.2%)	2.6001 (6.7%)	2.5746 (6.5%)	Live Variable Analysis
1.2680 (15.7%)	0.9920 (3.2%)	2.2601 (5.8%)	2.3452 (5.9%)	Live Interval Analysis
1.2320 (15.3%)	0.8440 (2.7%)	2.0761 (5.3%)	2.0690 (5.2%)	Linear Scan Register Allocator
1.0000 (12.4%)	0.6280 (2.0%)	1.6280 (4.1%)	1.5355 (3.8%)	Simple Register Coalescing
0.3680 (4.5%)	0.4320 (1.4%)	0.8000 (2.0%)	0.7780 (1.9%)	Control Flow Optimizer
8.0444 (100.0%)	30.7618 (100.0%)	38.8063 (100.0%)	39.5548 (100.0%)	TOTAL

No Parallel compilation

One big lock for JIT (and shared tables)

- JVM (MSIL) to LLVM IR
- Generating LLVM types
- Applying optimization passes
- Code generation

Missing features

- Non-calls exceptions
  - Null and div/0 runtime checks
- Arithmetic overflow
  - Runtime checks
- Bytecode checking
- Type-based alias analysis

Conclusion:
VMKit needs your participation!

- VMKit work
  - Thread optimizations
  - Generational GC with LLVM
- LLVM work
  - Hot-spotting LLVM
  - VM specific optimization passes
  - Non-calls exceptions
  - Compilation times

For more information

http://vmkit.llvm.org

Thank you: Tanya, Ted, ADC France, Apple Inc.