BEAMJIT: An LLVM based just-in-time compiler for Erlang

Frej Drejhammar
<frej@sics.se>

140407

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Who am I?

Senior researcher at the Swedish Institute of Computer Science (SICS) working on programming languages, tools and distributed systems.

Acknowledgments

- Project funded by Ericsson AB.
- Joint work with Lars Rasmusson `<lra@sics.se>`.

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What this talk is About

- Automatic synthesis of a JIT-compiling VM for Erlang.
- Our experiences with LLVM and MCJIT.

Outline

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Just-In-Time (JIT) Compilation

- Decide at runtime to compile “hot” parts to native code.
- Fairly common implementation technique.
    - Python (Psyco, PyPy)
    - Smalltalk (Cog)
    - Java (HotSpot)
    - JavaScript (SquirrelFish Extreme, SpiderMonkey)

Erlang

- Functional language developed by Ericsson.
- Soft real-time.
- Multi-threaded with share-nothing semantics.
- Message passing.
- Powerful supervision primitives.
- Hot code loading and replacement.
- OTP: Framework for writing fault-tolerant applications.
- Compiled to virtual machine (VM), BEAM.

BEAM: Specification & Implementation

- BEAM is the name of the Erlang VM.
- A register machine.
- Approximately 150 instructions which are specialized to around 450 macro-instructions using a peephole optimizer during code loading.
- Instructions are CISC-like.
- Hand-written C (mostly) directly threaded interpreter.
- No authoritative description of the semantics of the VM except the implementation source code!
- HiPE – a ahead-of-time native compiler
  - Traditional back-end for x86, PowerPC, SPARC, ARM
  - ErLLVM back-end based on LLVM

Motivation

- A JIT compiler increases flexibility.
- Compiled BEAM modules are platform independent.
- Cross-module optimization.
- Integrates naturally with code upgrade.

Project Goals

Goals:

- Do as little manual work as possible.
- Preserve the semantics of plain BEAM.
- Automatically stay in sync with the plain BEAM, i.e. if bugs are fixed in the interpreter the JIT should not have to be modified manually.
- Have a native code generator which is state-of-the-art.

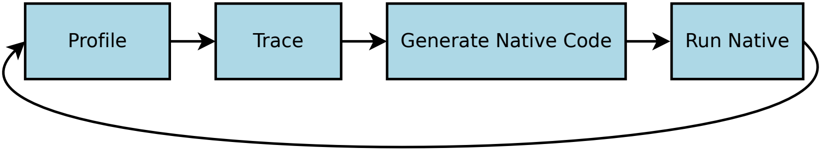
Plan:

- Parse and extract semantics from the C implementation.
- Transform the parsed C source to C fragments which are then reassembled into a replacement VM which includes a JIT-compiler.

Outline

Just-In-Time (JIT) Compilation as it Applies to BEAM

- Use light-weight profiling to detect when we are at a place which is frequently executed.
- Trace the flow of execution until we get back to the same place.
- Compile trace to native code.
- NOTE: We are tracing the execution flow in the interpreter, the granularity is finer than BEAM opcodes.



BEAMJIT: What is Needed?

- Three basic execution modes
  - Profiling
  - Tracing
  - Native
- Interpreter loop has to be modified to support mode switching:
  - Turn on/off tracing.
  - Passing state to/from native code.
- Native code generation: Need the semantics for each instruction.

Profiling

- First step in figuring out what to JIT-compile
- Let Erlang compiler insert profile instructions at locations which can be the head of a loop
- Maintain a time stamp and counter for each location
- Measure execution intensity by incrementing a counter if the location was visited recently, reset otherwise
- Trigger tracing when count is high enough
- Blacklist locations which:
  - Never produce a successful trace.
  - Where we, when executing native code, leave the trace without executing the loop at least once.

Outline

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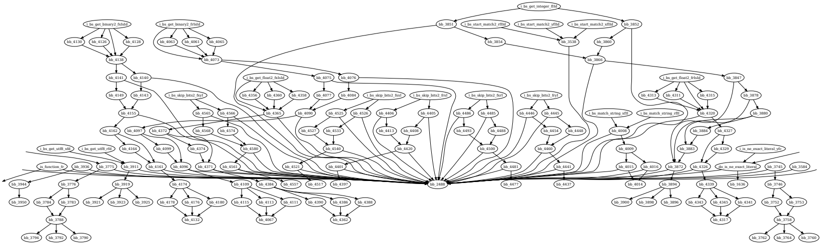
Extracting the Semantics of the BEAM Opcodes

Use libclang to parse and simplify the interpreter source:

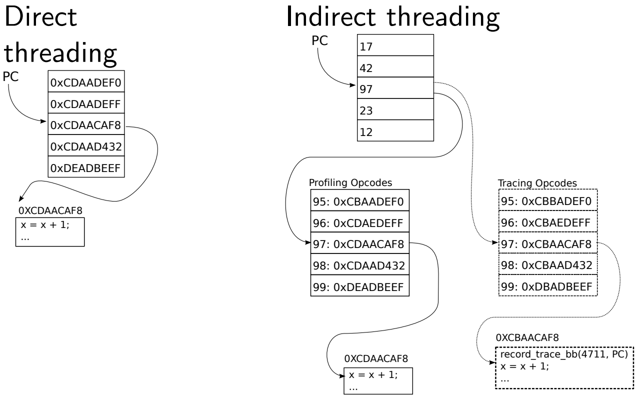
- Use Erlang binding for libclang.
- Flatten variable scopes.
- Remove loops, replace by if + goto.
- Make fall-troughs explicit.
- Turn structured C into a spaghetti of Basic Blocks (BB), CFG – Control Flow Graph.
- Do liveness-analysis of variables.



Naïve Tracing

- Use a new version of the interpreter, generated from the CFG.
- Generate a tracing and non-tracing version of each opcode.
- For each basic block we pass through, record basic block identity and PC.
- Abort trace if too long.
- If we reach the profile instruction we started the trace from – We have found a loop!

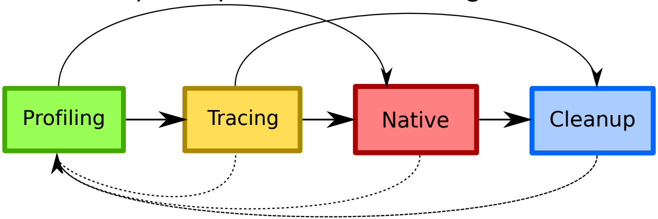
Naïve Profiling to Tracing Mode Switch



- Have two implementations of each opcode.
- Switch the table of opcodes.
- Compiler has to assume that a mode switch can take place at any block $\rightarrow$ performance suffers

Refined Tracing

- Modify the interpreter loop as little as possible.
- Have separate trace interpreter.
- Limit entry to the interpreter at instruction boundaries.
- Have separate *cleanup*-interpreter to continue execution to the next instruction boundary.
- Reuse *cleanup*-interpreter when returning from native mode.



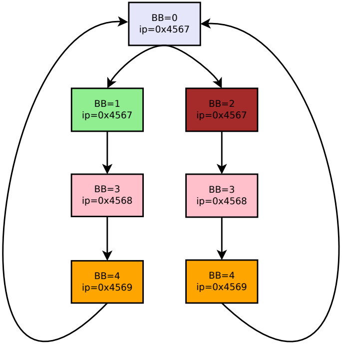
Further Tracing Refinements

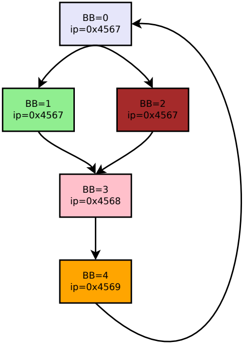
Ensure that we have a representative trace:

- Follow along a previously created trace.
- Allow multi-path traces.
- Generate native code when the trace has not grown for N successive iterations.
- Enforce limit on total size of trace.

Trace Compression

- Large CFGs slow down LLVM optimization and native code generation significantly.
- Solution: Compress traces to remove shared segments.

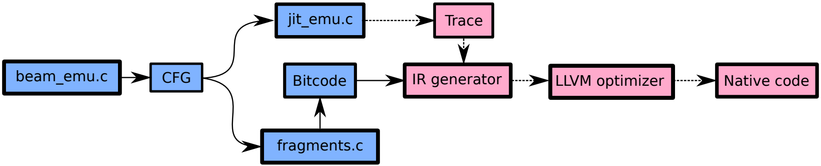




Outline

Native-code Generation

- Glue together LLVM-IR-fragments for the trace.
- *Guards* are inserted to make sure we stay on the traced path.
- Fragments are extracted from the CFG as C-source, compiled to IR using clang (at build-time) and loaded during system initialization.
- Hand the resulting IR off to LLVM for the rest.



Calling Native Code

Switching from interpreter to native code:

- Use liveness information from the CFG.
- Package native-code as a function where the arguments are the live variables.

Switching from native code to interpreter:

- The cleanup-interpreter is a set of functions, one for each BB, which tail-recursively calls the next BB. Arguments are the live variables.
- Cleanup-interpreter packs up live variables in a structure which the interpreter unpacks on return.

Performance Improvements

- Run native-code generation in separate thread.
- Erlang-aware constant propagation:
  - Eliminate loads from code (constant at compile time).
  - Will eliminate loading of immediates.
  - Will eliminate many of the guards.

Performance

Steady state:

- Eliminates most of the instruction decode overhead.
- Up to 50% reduction in runtime.
- Well-behaved programs: around 25%.
- Programs using cute tricks such as unrolling: up to 200% increase in runtime.

Future Work

- Full SMP support.
- Box/unboxing-aware constant propagation.
- Extend JIT support to fold in primitives.

Outline

LLVM's Strengths

- Access to the C AST via libClang.
- Quality of generated code.
- The optimization framework.

LLVM's Weaknesses

- No thread-safety – Extra housekeeping to do things in the correct context.
- Compilation could be much faster.
- Native code has to be packaged as C-function – Would really like to have enough control to patch generated native code.
- Clang/LLVM does bad job on the main interpreter:
  - Allocates the VM's stack- and instruction-pointers on the stack.
  - Inserts extra instruction sequence before indirect jumps (when dispatching to next VM instruction), GCC appears to insert it at the branch target and only if needed.

  Costs us 15-20%

Outline

Questions?