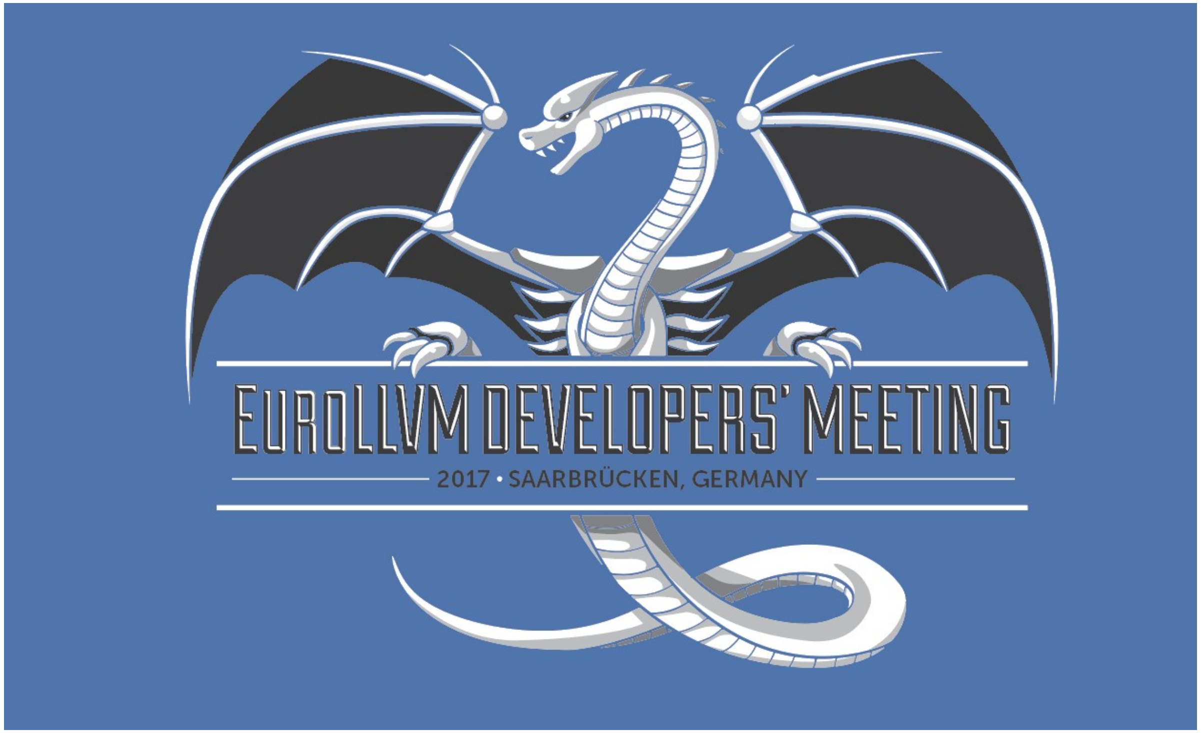
Clank: Java-port of C/C++ Frontend

Sharing the NetBeans Team’s Experience

Petr Kudriavtsev
Vladimir Voskresensky
Oracle



March 27, 2017

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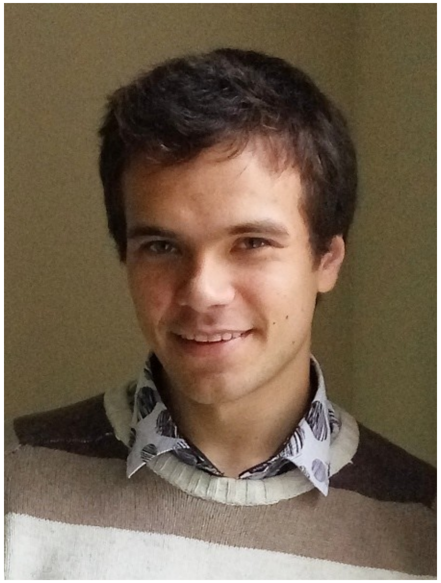
Speakers



Petr Kudriavtsev

Vladimir Voskresensky

Agenda

- Why porting?
- Known approaches
- Converter
- Porting C++ and Clang challenges
- Clank Demo

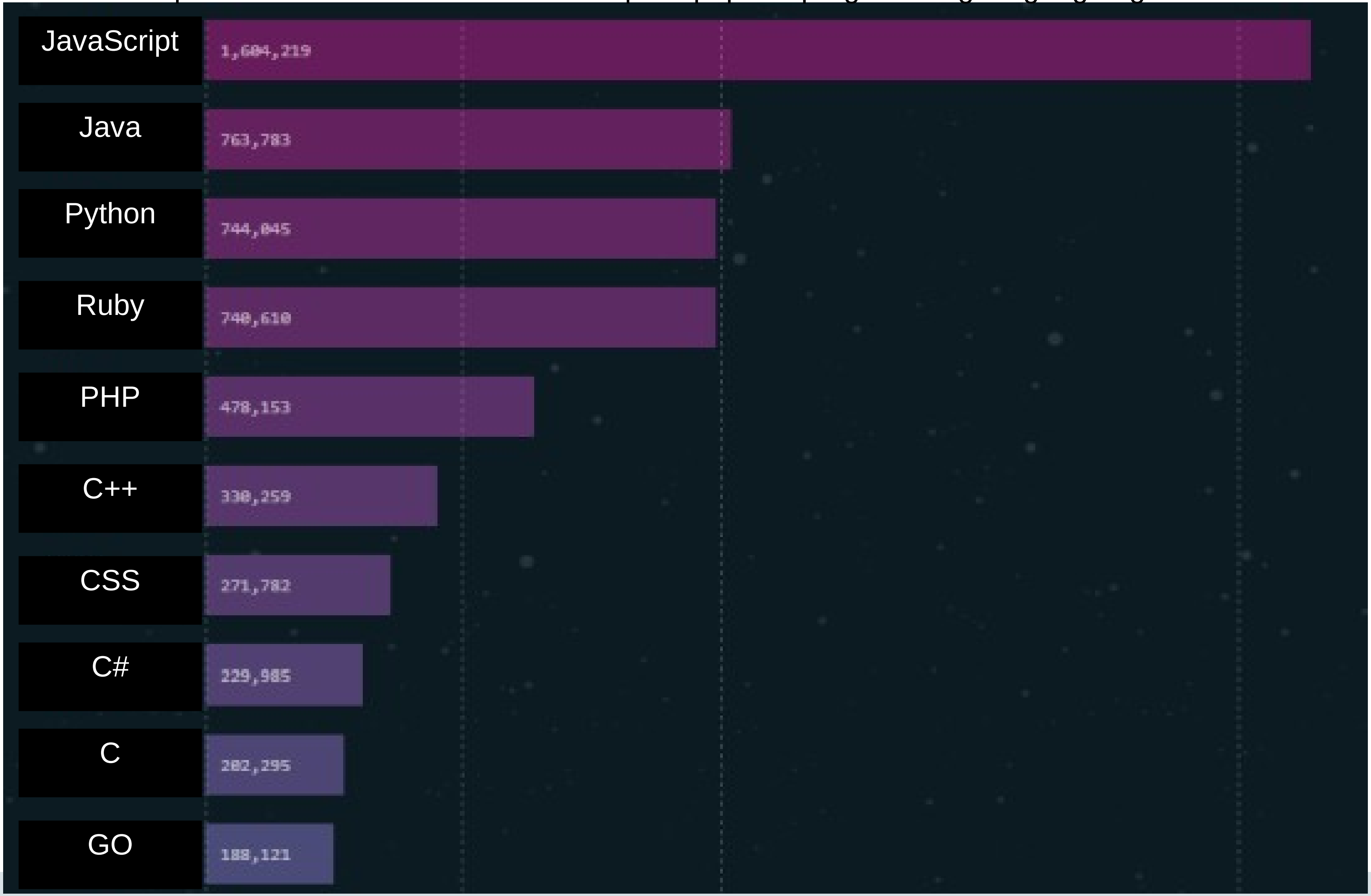
Why not binding?

- Why Emscripten?
  - LLVM IR to JavaScript 'assembler'?
- Why Lucene => CLucene?
  - Java ported to C++?
- Why Hibernate => NHibernate?
  - Java ported to .NET?
- Why people do porting?
  - It's fun!

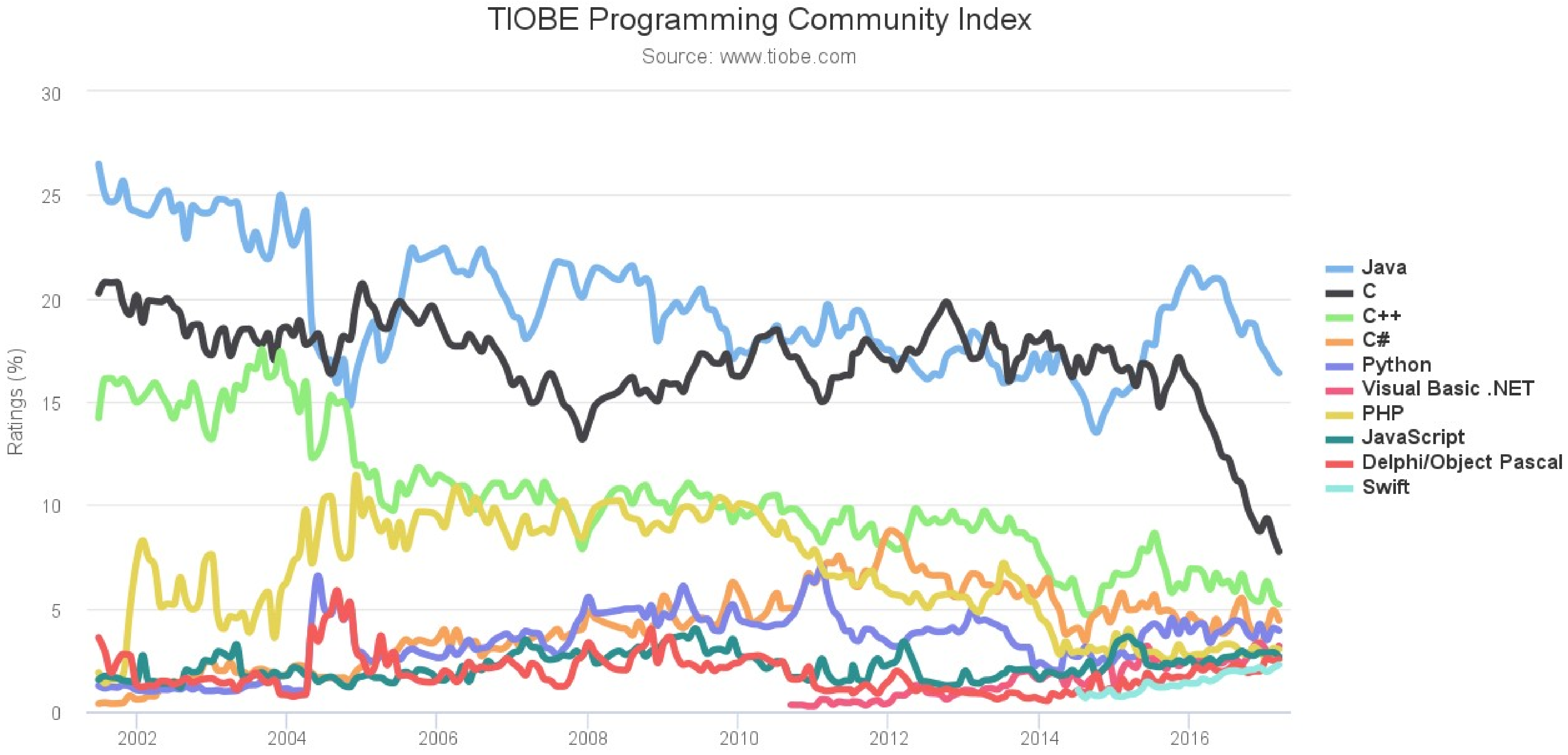
C++ and 2*C == Java

The 10 most popular computer languages on GitHub

https://www.techworm.net/2016/09/top-10-popular-programming-languages-github.html



C++ and C == Java


TIOBE Programming Community Index
Source: www.tiobe.com
Ratings (%)
30
25
20
15
10
5
0
2002
2004
2006
2008
2010
2012
2014
2016
Java
C
C++
C#
Python
Visual Basic .NET
PHP
JavaScript
Delphi/Object Pascal
Swift

What is our favorite C++ Technology?

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No religious wars!
Let's share Clang Technology

Add One More Thread Holding Developers Together

Clang Technology evaluation

- Native Clang library requirements without functional regressions:
  - Full access to the strength of technology
  - All Java-aware platforms
  - Safety
  - Debug
  - Performance of native clang
  - JNI/JNA Bridging overhead
  - Upgrade to new Clang release

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Conclusion: Clang doesn't bring any extra value?

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Wait! Let's try Clang in Java!

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Agenda

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- **Known approaches**
- Converter
- Porting C++ and Clang challenges
- Clank Demo

Manual

- Inspired by ...

Manual

LLVM IR Based

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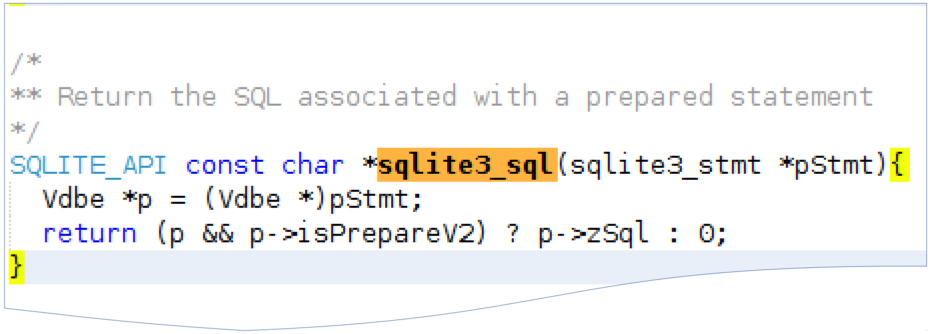
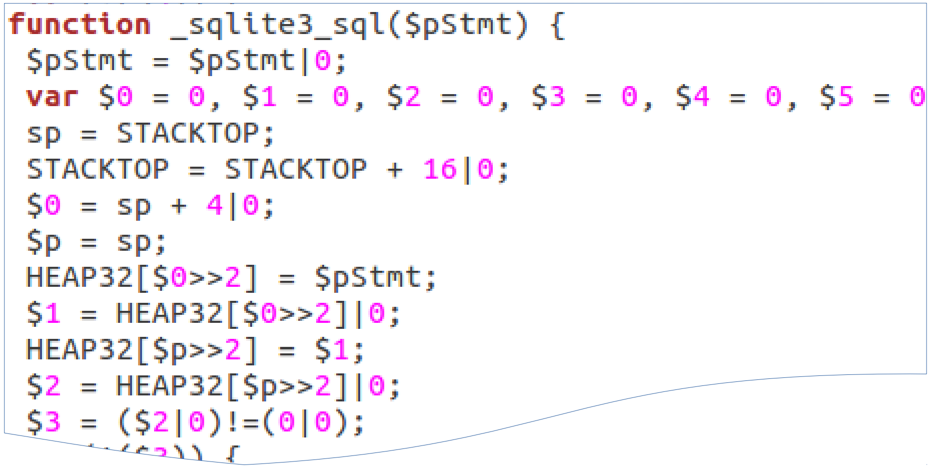
- Transform LLVM IR to Java Bytecode
- Assembler Level Output
  - Difficult to understand
  - Difficult to debug by client

C++



```
/*
** Return the SQL associated with a prepared statement
*/
SQLITE_API const char *sqlite3_sql(sqlite3_stmt *pStmt){
  Vdbe *p = (Vdbe *)pStmt;
  return (p && p->isPrepareV2) ? p->zSql : 0;
}
```

JavaScript



```
function _sqlite3_sql($pStmt) {
 $pStmt = $pStmt|0;
 var $0 = 0, $1 = 0, $2 = 0, $3 = 0, $4 = 0, $5 = 0
 sp = STACKTOP;
 STACKTOP = STACKTOP + 16|0;
 $0 = sp + 4|0;
 $p = sp;
 HEAP32[$0>>2] = $pStmt;
 $1 = HEAP32[$0>>2]|0;
 HEAP32[$p>>2] = $1;
 $2 = HEAP32[$p>>2]|0;
 $3 = ($2|0)!=(0|0);
```

LLVM IR Based

- Inspired by Emscripten
- Transform LLVM IR to Java Bytecode
- Assembler Level Output
  - Difficult to understand
  - Difficult to debug by client
- Java AST* APIs are needed to be generated from C-like IR back to Java Classes/methods

Existing C++ to Java Converters

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Low Accuracy on C++11 Codebases

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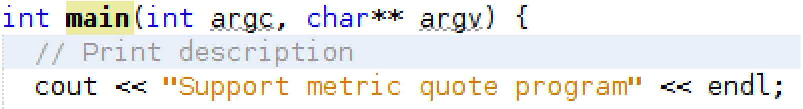
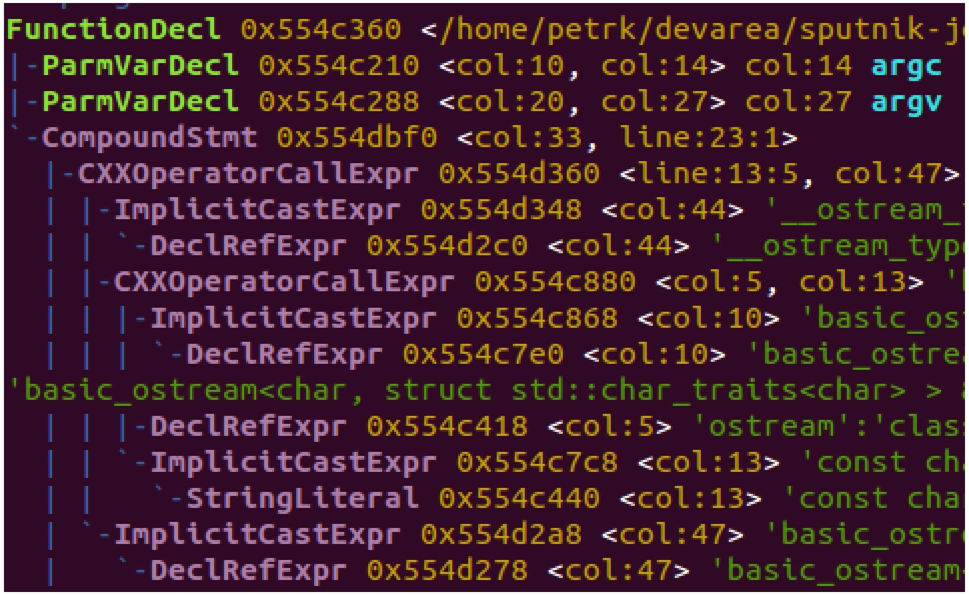
C++:



```
int main(int argc, char** argv) {
  // Print description
  cout << "Support metric quote program" << endl;
```

AST:



```
FunctionDecl 0x554c360 </home/petrk/devarea/sputnik-j
|-ParmVarDecl 0x554c210 <col:10, col:14> col:14 argc
|-ParmVarDecl 0x554c288 <col:20, col:27> col:27 argv
`-CompoundStmt 0x554dbf0 <col:33, line:23:1>
  |-CXXOperatorCallExpr 0x554d360 <line:13:5, col:47>
  | |-ImplicitCastExpr 0x554d348 <col:44> '__ostream_
  | | `-DeclRefExpr 0x554d2c0 <col:44> '__ostream_typ
  | |-CXXOperatorCallExpr 0x554c880 <col:5, col:13> '
  | | |-ImplicitCastExpr 0x554c868 <col:10> 'basic_os
  | | | `-DeclRefExpr 0x554c7e0 <col:10> 'basic_ostre
'basic_ostream<char, struct std::char_traits<char> >
  | | |-DeclRefExpr 0x554c418 <col:5> 'ostream':'clas
  | | `-ImplicitCastExpr 0x554c7c8 <col:13> 'const ch
  | |   `-StringLiteral 0x554c440 <col:13> 'const cha
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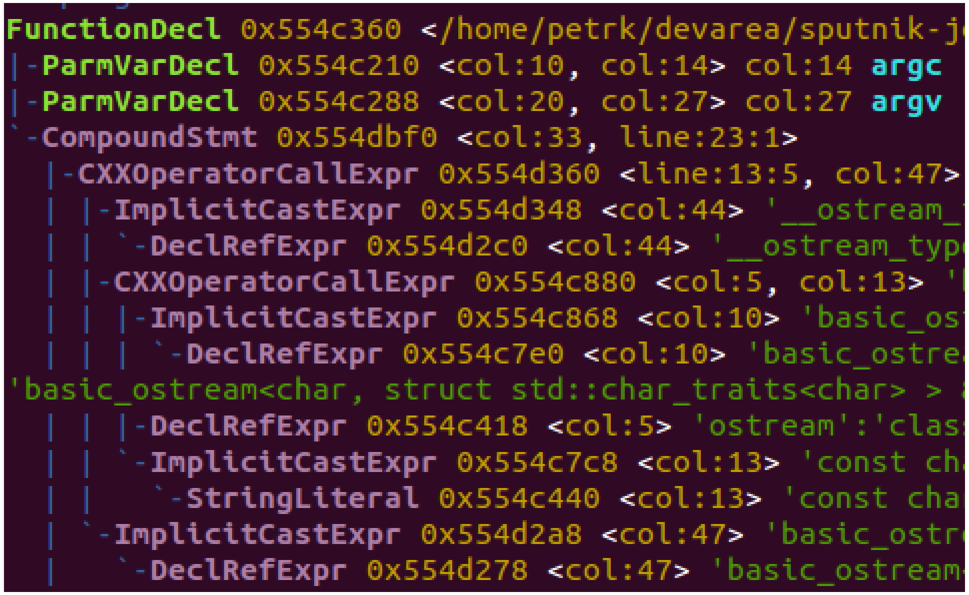
Clang Based

- Inspired by ast-print
  - Clang: C++ Source to Clang-AST
  - ast-print: Clang-AST to C++ source

AST:



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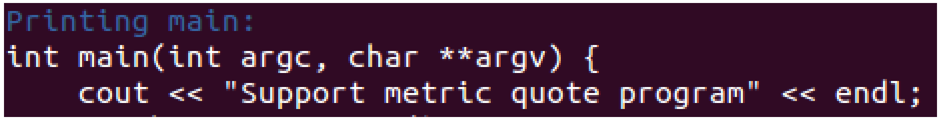

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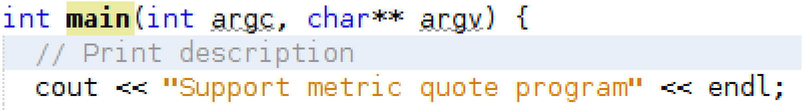

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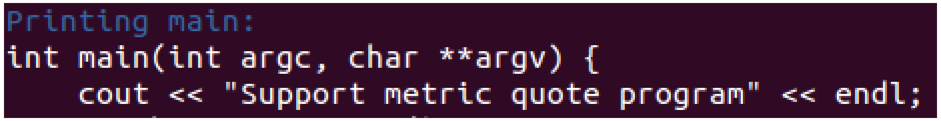
Printed C++:



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Convert whole Clang-AST
to Java Source!

Agenda

- Why porting?
- Known approaches
- **Converter**
- Porting C++ and Clang challenges
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Prototype Converter

- Within 1 day
  - Always print method bodies in class context to make Java happy
  - Replace arrow “→” by “.” to make Java happy

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  - And I'm going on vacation

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Team conclusion: Don't bother us with your crazy dreams!
It is still manual!

Need a Plan…

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- Bottom up approach
  - for API

Llvm ADT/Support

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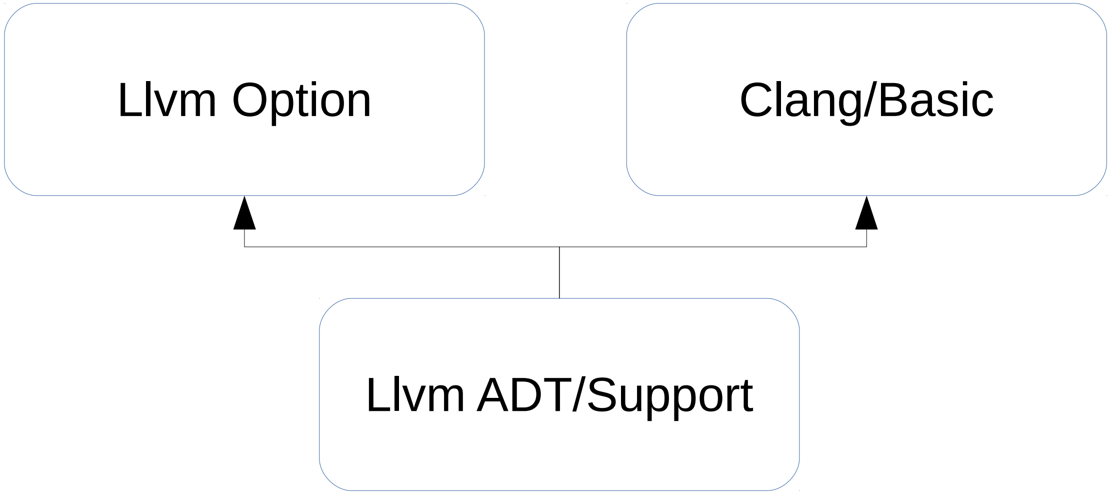
  - for API



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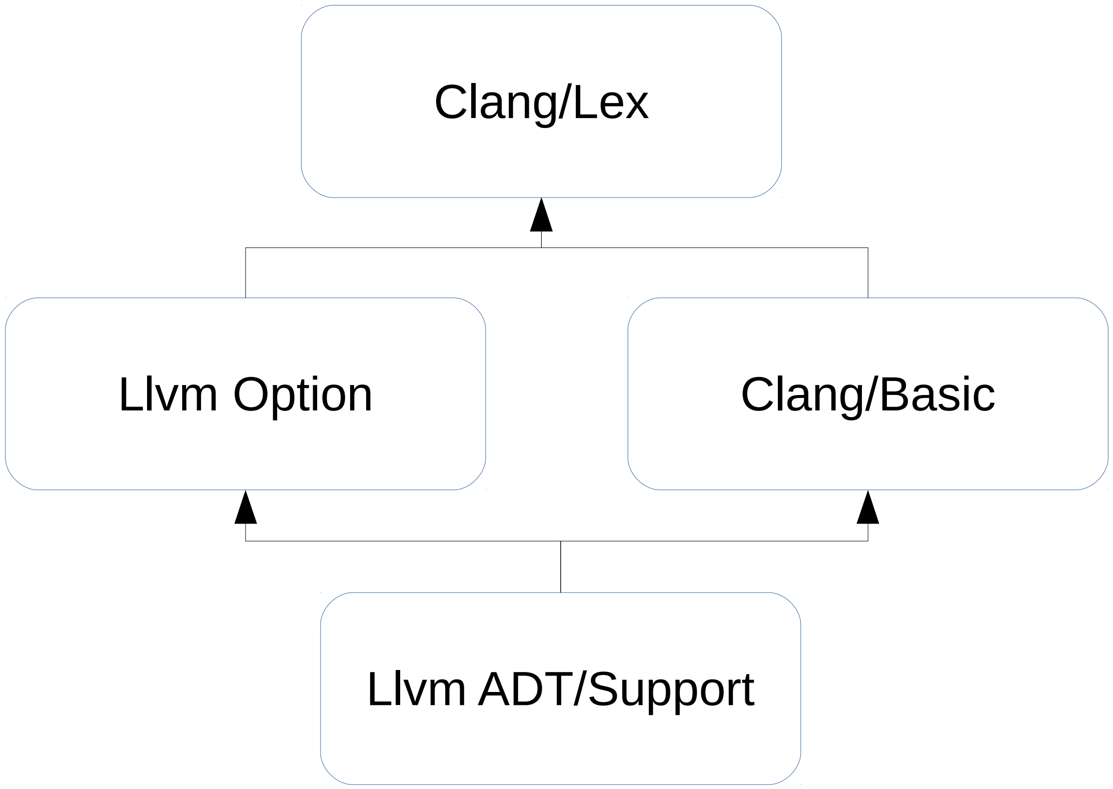
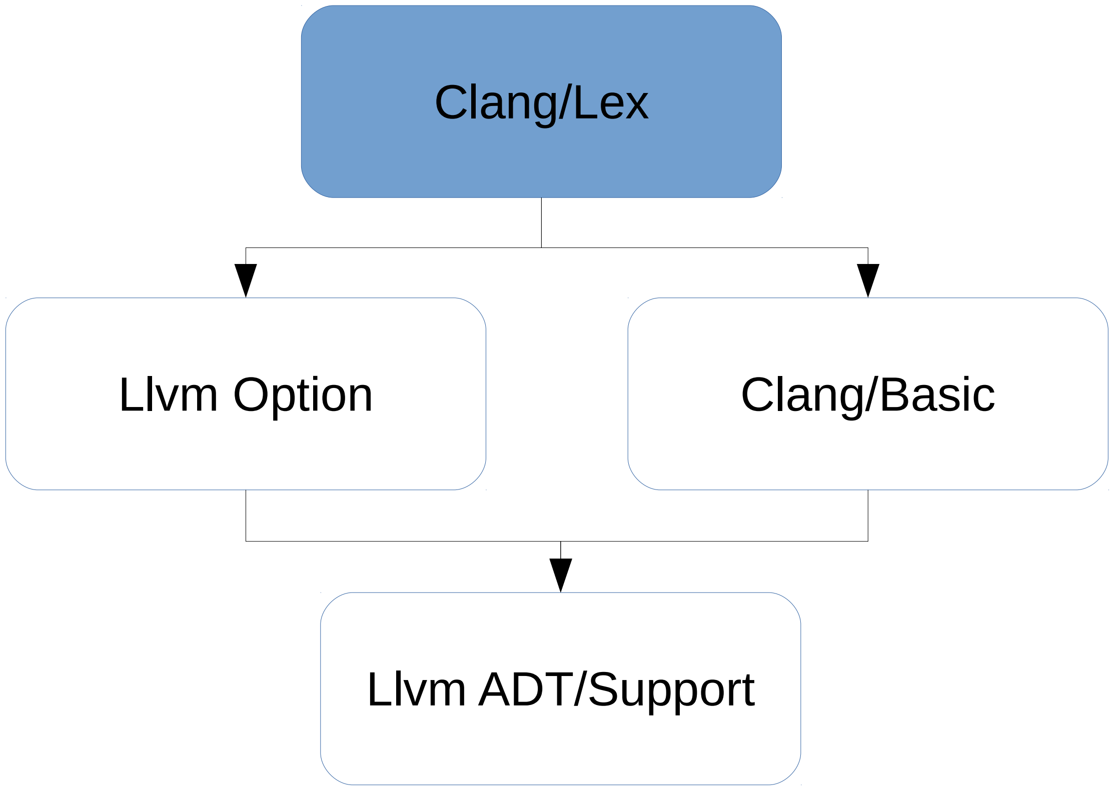


Need a Plan...

- Followed by Top down approach
  - for implementations



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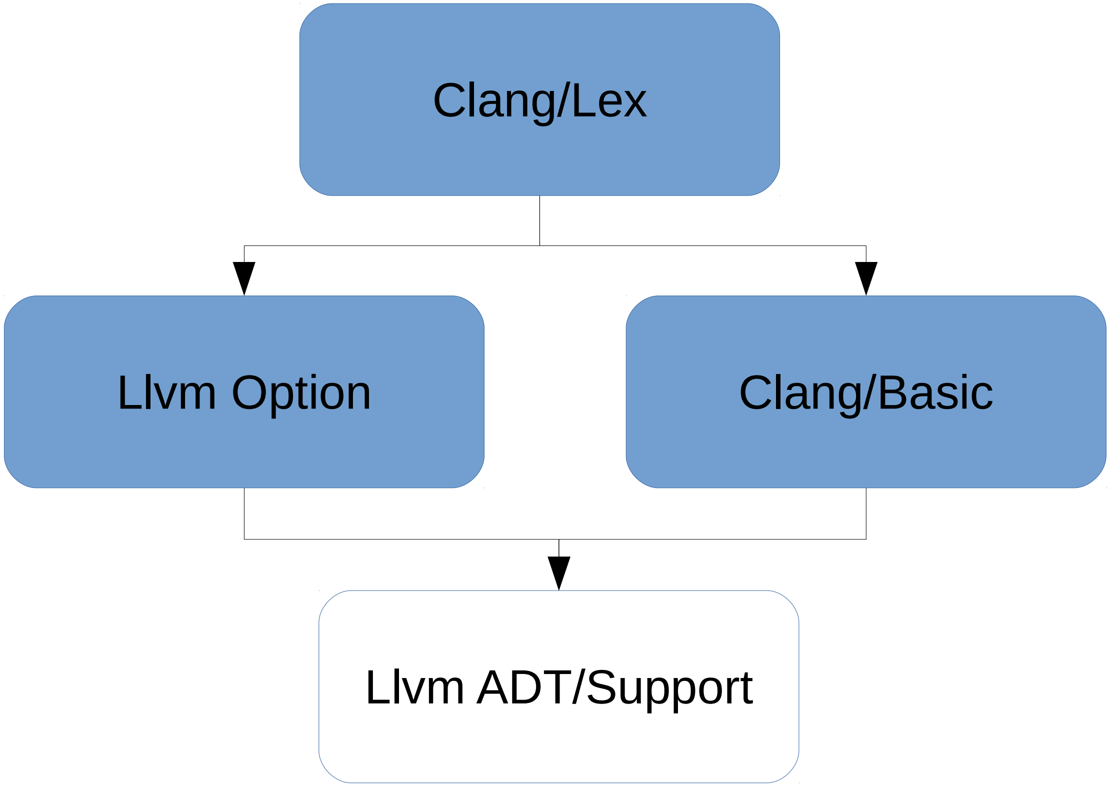

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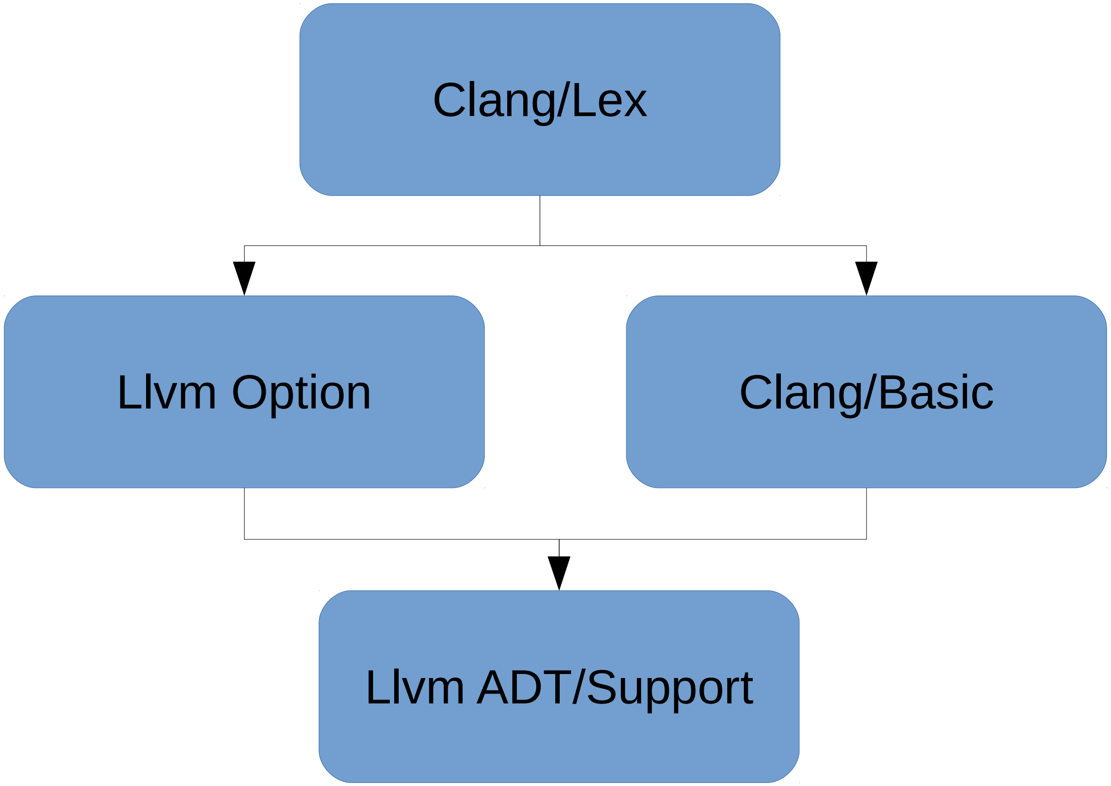


Need a Plan...

- Bottom up approach
  - Generate APIs without bodies
- Followed by Top down approach
  - Generate bodies starting from clients
    - Let's try Lex module
    - To build infrastructure
    - To evaluate ported Preprocessor
  - Adjusting APIs when better learn Clang/LLVM
    - Easy, fast, because bodies are absent
    - Add Java's “LibC++” and ADT/Support on demand
- Use existing Clang tests to check semantic
- Annotate Java code to get help from IDE
- Release within NetBeans C++ support

Same Time at Different World...

- Use Clang technology to parse C++
- Walk Clang AST to print Java code

During Short Nights...

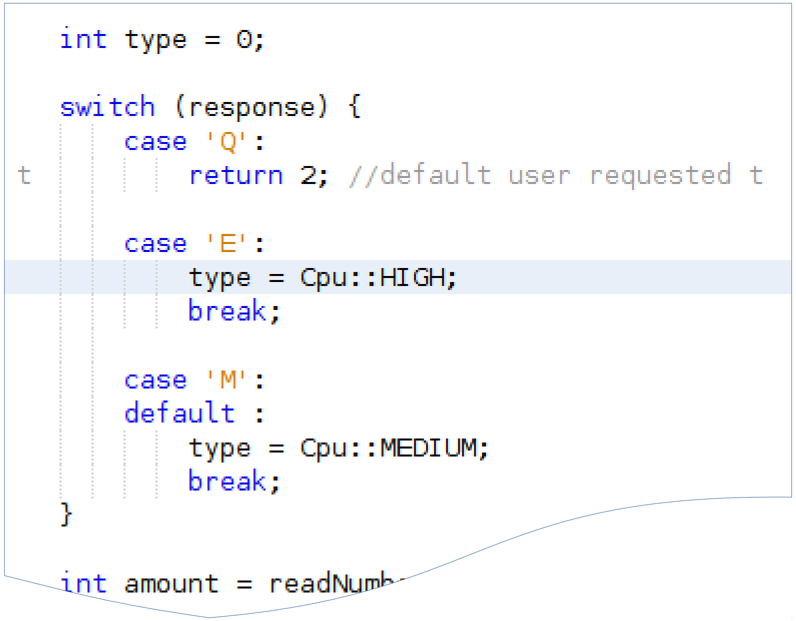
- Use Clang technology to parse C++
- Walk Clang AST to print Java code
- 2 weeks to prototype JConvert
  - Port sample C++ project to Java
  - Keep semantic
  - Keep code as close as possible
  - Keep comments

And Long Weekends...

- Use Clang technology to parse C++
- Walk Clang AST to print Java code
- 2 weeks to prototype JConvert
  - Port sample C++ project to Java
  - Keep semantic
  - Keep code as close as possible
  - Keep comments
- Demo

JConvert 0.0.1

- C++ Quote vs Java Quote snippets



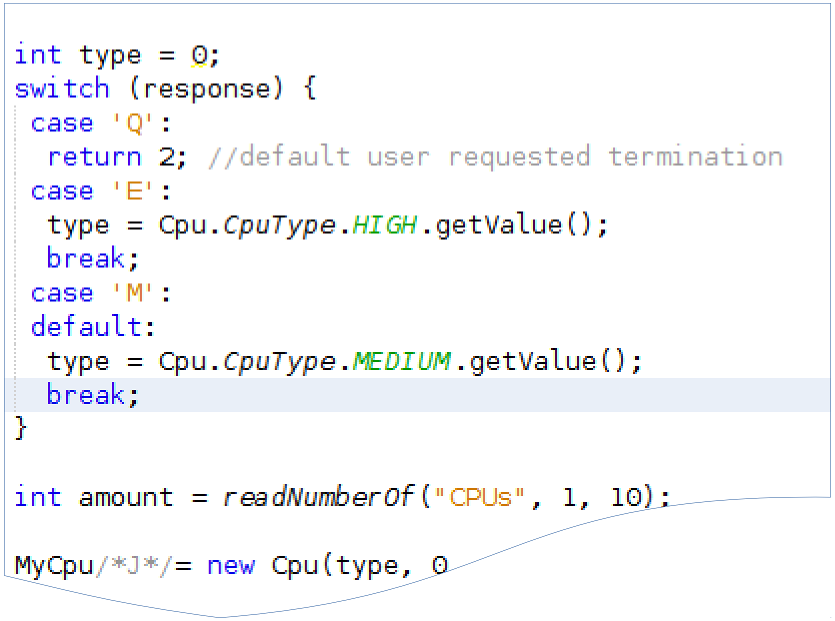
```
   int type = 0;

   switch (response) {
       case 'Q':
t          return 2; //default user requested t

       case 'E':
           type = Cpu::HIGH;
           break;

       case 'M':
       default :
           type = Cpu::MEDIUM;
           break;
   }

   int amount = readNumb
```



```
int type = 0;
switch (response) {
 case 'Q':
  return 2; //default user requested termination
 case 'E':
  type = Cpu.CpuType.HIGH.getValue();
  break;
 case 'M':
 default:
  type = Cpu.CpuType.MEDIUM.getValue();
  break;
}

int amount = readNumberOf("CPUs", 1, 10);

MyCpu/*J*/= new Cpu(type, 0
```

It works for sample C++ project!

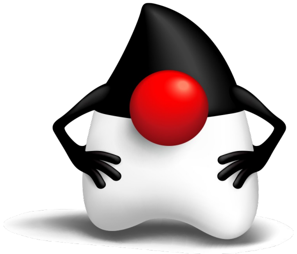
Agenda

- Why porting?
- Known approaches
- Converter
- **Porting C++ and Clang challenges**
- Clank Demo

Clang - Pronunciation: /klaNG/

A loud, resonant metallic sound or series of sounds

- Oxford Dictionary



Clank - Pronunciation: /klaNGk/

A loud, sharp sound or series of sounds, typically made by pieces of metal meeting or being struck together

- Oxford Dictionary

Clank: As close to origin as possible

- Convert Clang components for fully functional Preprocessor
  - Keeps comments
  - Semantically equivalent
  - Passes Clang tests
- Pure Java
  - Modular
  - Java “LibC++”
- Adopted by NetBeans
- The same License as LLVM
  - “Wanted the code to be **used!**” quoting Chris Lattner

“All hope abandon, ye who enter here.”

— Dante Alighieri, The Divine Comedy

C++ in Java Challenges

- Names collisions
  - Non-virtual methods in base and derived classes
    - In Java all methods are virtual
  - 'unsigned int' vs 'int' overloaded methods and constructors
- Diagnostics are not printed
  - Temporary objects lifecycle
- Multiple inheritance
- Compile time preprocessor-conditional code in FileSystem
  - Changed #ifdef/#else/#endif to runtime
- Split by TUs vs Monolithic Java classes
- this+1 and TrailingObjects
- Custom new operators
- **JAVA code Performance**

Clank: All is solvable

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- ✓ Custom new operators
- ✓ JAVA Clank Preprocessor Performance

Clank: All is solvable

Complete and fast Clank Preprocessor, 1.1 MLoc, integrated into NetBeans

✓ Names collisions
  - Non-virtual methods in base and derived classes
    - In Java all methods are virtual
  - 'unsigned int' vs 'int' overloaded methods and constructors

✓ Diagnostics are not printed
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✓ Compile time preprocessor-conditional code in FileSystem
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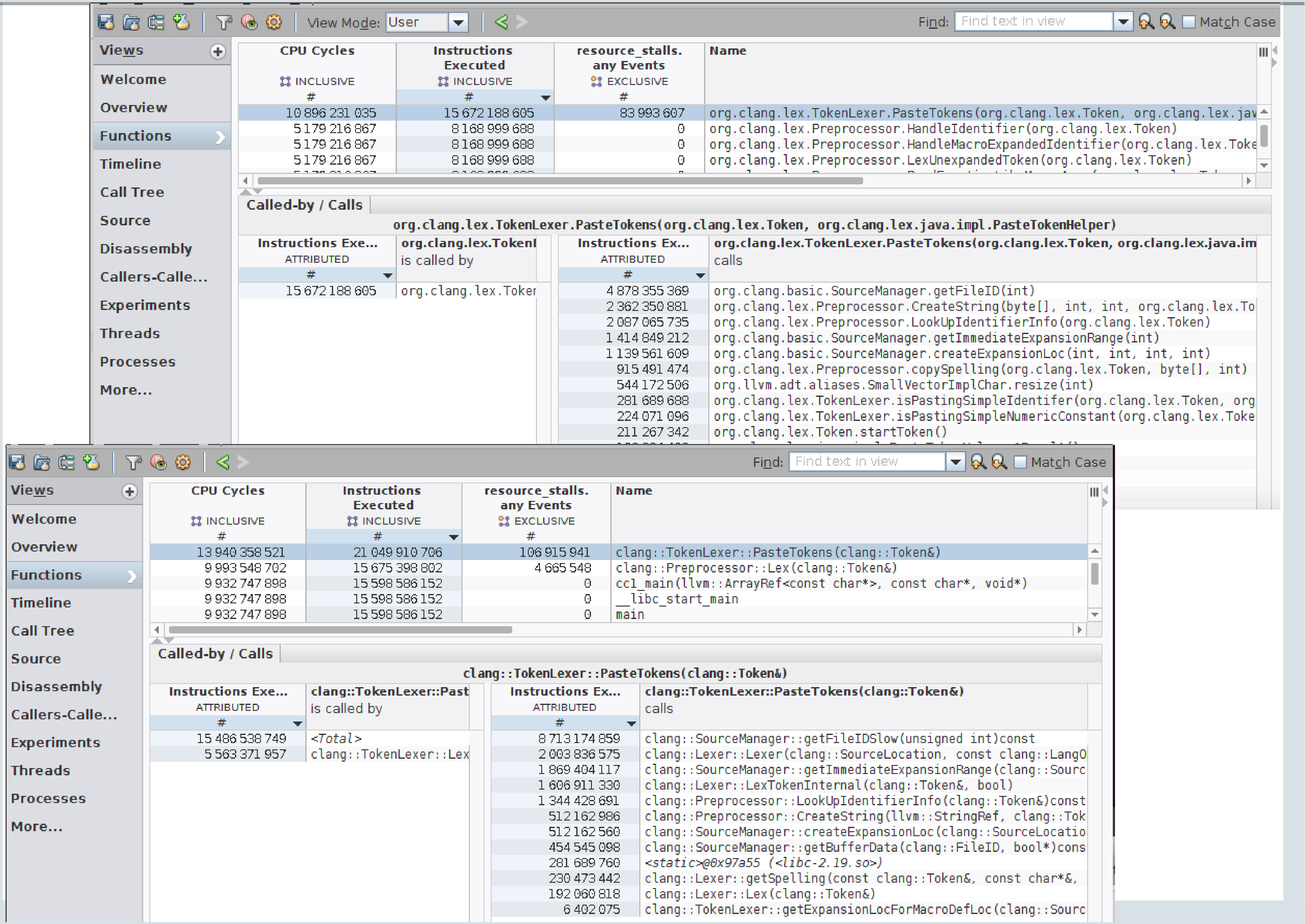
✓ Custom new operators

✓ JAVA Clank Preprocessor Performance



CPU Cycles INCLUSIVE #	Instructions Executed INCLUSIVE #	resource_stalls. any Events EXCLUSIVE #	Name
10 896 231 035	15 672 188 605	83 993 607	org.clang.lex.TokenLexer.PasteTokens(org.clang.lex.Token, org.clang.lex.jav
5 179 216 867	8 168 999 688	0	org.clang.lex.Preprocessor.HandleIdentifier(org.clang.lex.Token)
5 179 216 867	8 168 999 688	0	org.clang.lex.Preprocessor.HandleMacroExpandedIdentifier(org.clang.lex.Toke
5 179 216 867	8 168 999 688	0	org.clang.lex.Preprocessor.LexUnexpandedToken(org.clang.lex.Token)

org.clang.lex.TokenLexer.PasteTokens(org.clang.lex.Token, org.clang.lex.java.impl.PasteTokenHelper)

Instructions Exe... ATTRIBUTED #	org.clang.lex.TokenI is called by
15 672 188 605	org.clang.lex.Toker

Instructions Ex... ATTRIBUTED #	org.clang.lex.TokenLexer.PasteTokens(org.clang.lex.Token, org.clang.lex.java.im calls
4 878 355 369	org.clang.basic.SourceManager.getFileID(int)
2 362 350 881	org.clang.lex.Preprocessor.CreateString(byte[], int, int, org.clang.lex.To
2 087 065 735	org.clang.lex.Preprocessor.LookUpIdentifierInfo(org.clang.lex.Token)
1 414 849 212	org.clang.basic.SourceManager.getImmediateExpansionRange(int)
1 139 561 609	org.clang.basic.SourceManager.createExpansionLoc(int, int, int, int)
915 491 474	org.clang.lex.Preprocessor.copySpelling(org.clang.lex.Token, byte[], int)
544 172 506	org.llvm.adt.aliases.SmallVectorImplChar.resize(int)
281 689 688	org.clang.lex.TokenLexer.isPastingSimpleIdentifer(org.clang.lex.Token, org
224 071 096	org.clang.lex.TokenLexer.isPastingSimpleNumericConstant(org.clang.lex.Toke
211 267 342	org.clang.lex.Token.startToken()

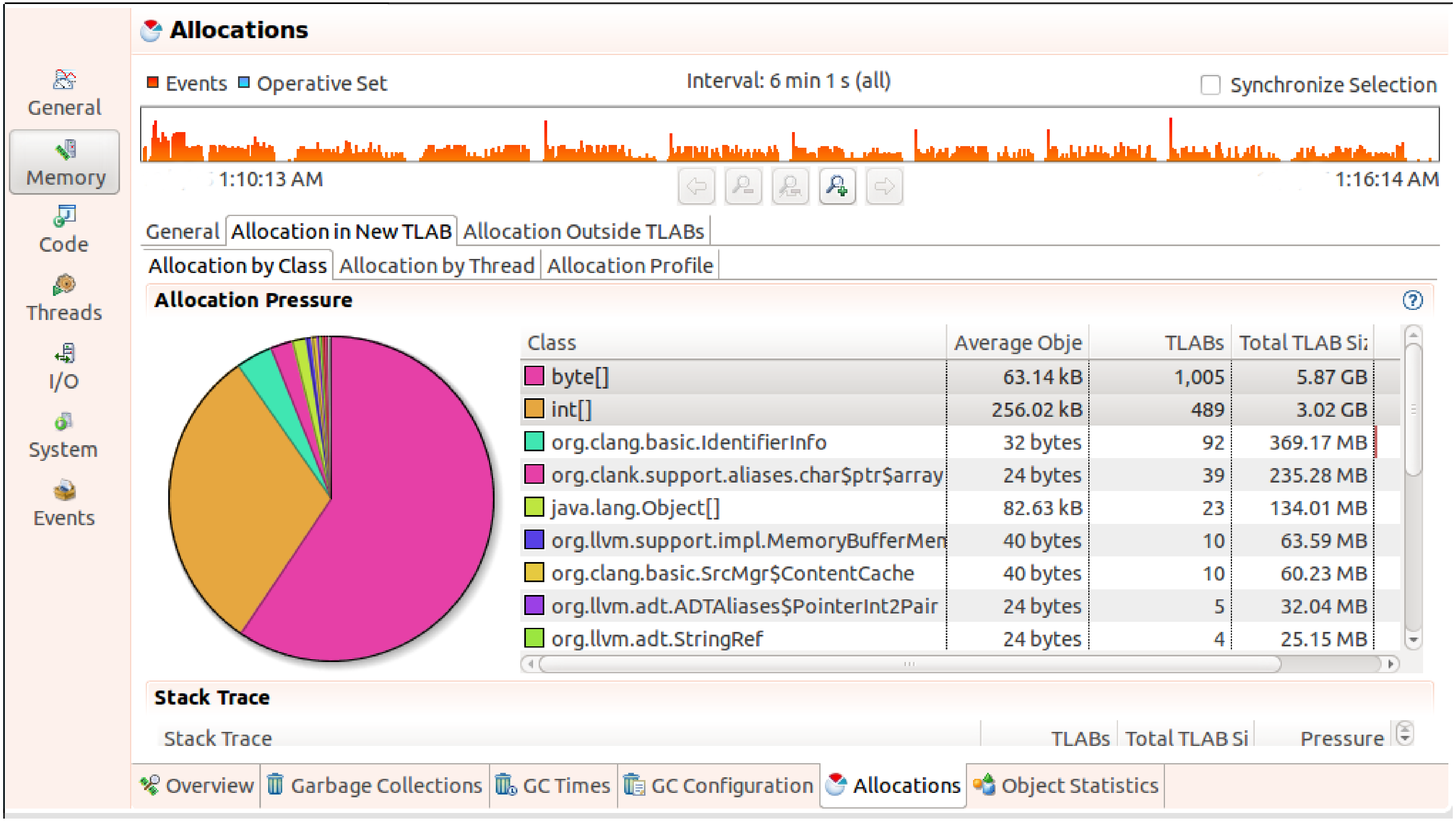
CPU Cycles INCLUSIVE #	Instructions Executed INCLUSIVE #	resource_stalls. any Events EXCLUSIVE #	Name
13 940 358 521	21 049 910 706	106 915 941	clang::TokenLexer::PasteTokens(clang::Token&)
9 993 548 702	15 675 398 802	4 665 548	clang::Preprocessor::Lex(clang::Token&)
9 932 747 898	15 598 586 152	0	cc1_main(llvm::ArrayRef<const char*>, const char*, void*)
9 932 747 898	15 598 586 152	0	__libc_start_main
9 932 747 898	15 598 586 152	0	main

clang::TokenLexer::PasteTokens(clang::Token&)

Instructions Exe... ATTRIBUTED #	clang::TokenLexer::Past is called by
15 486 538 749	*<Total>*
5 563 371 957	clang::TokenLexer::Lex

Instructions Ex... ATTRIBUTED #	clang::TokenLexer::PasteTokens(clang::Token&) calls
8 713 174 859	clang::SourceManager::getFileIDSlow(unsigned int)const
2 003 836 575	clang::Lexer::Lexer(clang::SourceLocation, const clang::LangO
1 869 404 117	clang::SourceManager::getImmediateExpansionRange(clang::Sourc
1 606 911 330	clang::Lexer::LexTokenInternal(clang::Token&, bool)
1 344 428 691	clang::Preprocessor::LookUpIdentifierInfo(clang::Token&)const
512 162 986	clang::Preprocessor::CreateString(llvm::StringRef, clang::Tok
512 162 560	clang::SourceManager::createExpansionLoc(clang::SourceLocatio
454 545 098	clang::SourceManager::getBufferData(clang::FileID, bool*)cons
281 689 760	*<static>@0x97a55 (<libc-2.19.so>)*
230 473 442	clang::Lexer::getSpelling(const clang::Token&, const char*&,
192 060 818	clang::Lexer::Lex(clang::Token&)
6 402 075	clang::TokenLexer::getExpansionLocForMacroDefLoc(clang::Sourc

Clank Memory Profiling



Class	Average Obje	TLABs	Total TLAB Si
🟥 byte[]	63.14 kB	1,005	5.87 GB
🟧 int[]	256.02 kB	489	3.02 GB
🟩 org.clang.basic.IdentifierInfo	32 bytes	92	369.17 MB
🟥 org.clank.support.aliases.char$ptr$array	24 bytes	39	235.28 MB
🟩 java.lang.Object[]	82.63 kB	23	134.01 MB
🟦 org.llvm.support.impl.MemoryBufferMen	40 bytes	10	63.59 MB
🟨 org.clang.basic.SrcMgr$ContentCache	40 bytes	10	60.23 MB
🟪 org.llvm.adt.ADTAliases$PointerInt2Pair	24 bytes	5	32.04 MB
🟩 org.llvm.adt.StringRef	24 bytes	4	25.15 MB

Stack Trace	TLABs	Total TLAB Si	Pressure

Clank: Performance analysis and optimizations in Java code

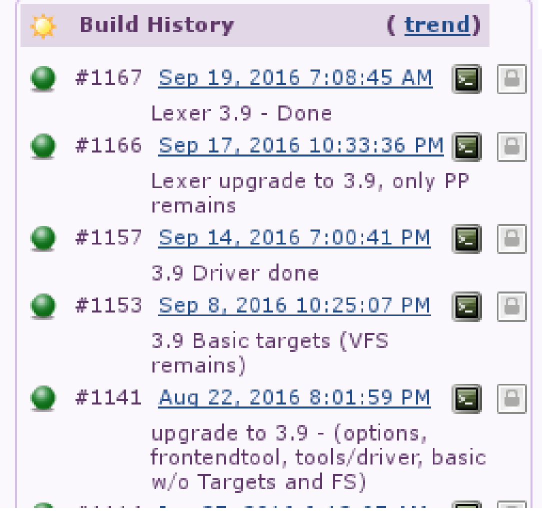
- Use Performance Analyzer to compare with Clang
  - PerfAn profiles Java or C++ using sampling with 2% overhead
  - Compare Instructions and CPU Cycles and do local perf optimizations
- Use Java Flight Recorder to profile memory footprint
- Teach Converter to produce more optimal code
- Use specializations based on parametrized spec files
  - Change template file, all specializations are regenerated
  - Add mapping to generate specializations, regenerate code

Clank: All is solvable

- ✓ Names collisions
  - Non-virtual methods in base and derived classes
    - In Java all methods are virtual
  - 'unsigned int' vs 'int' overloaded methods and constructors
- ✓ Diagnostics are not printed
  - Temporary objects lifecycle
- ✓ Multiple inheritance
- ✓ Compile time preprocessor-conditional code in FileSystem
  - Changed #ifdef/#else/#endif to runtime
- ✓ Split by TUs vs Monolithic Java classes
- ✓ this+1 and TrailingObjects
- ✓ Custom new operators
- ✓ JAVA Clank Preprocessor Performance

Clank: Upgrade to Clang 3.9

- Tooling
  - Analyze diffs
  - Analyze dependencies
  - Detect Changed Entities
  - Prepare TODO actions
  - Process Moved and Renamed actions first
  - Drive upgrade
  - Mark progress
  - Track progress



Build History (trend)

#1167 Sep 19, 2016 7:08:45 AM
Lexer 3.9 - Done

#1166 Sep 17, 2016 10:33:36 PM
Lexer upgrade to 3.9, only PP remains

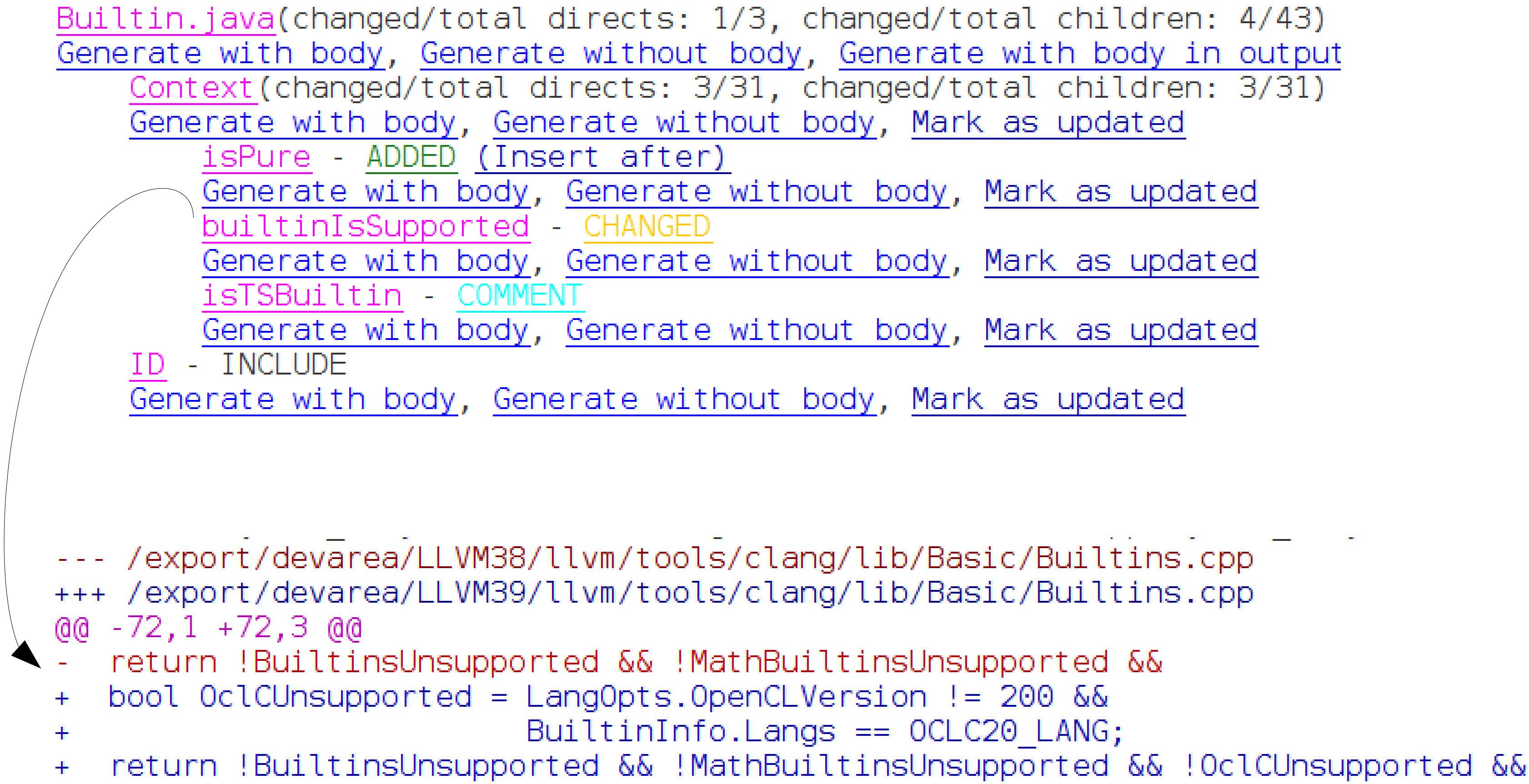
#1157 Sep 14, 2016 7:00:41 PM
3.9 Driver done

#1153 Sep 8, 2016 10:25:07 PM
3.9 Basic targets (VFS remains)

#1141 Aug 22, 2016 8:01:59 PM
upgrade to 3.9 - (options, frontendtool, tools/driver, basic w/o Targets and FS)

Clank: Upgrade to Clang 3.9

- Update view



```
Builtin.java(changed/total directs: 1/3, changed/total children: 4/43)
Generate with body, Generate without body, Generate with body in output
    Context(changed/total directs: 3/31, changed/total children: 3/31)
    Generate with body, Generate without body, Mark as updated
        isPure - ADDED (Insert after)
        Generate with body, Generate without body, Mark as updated
        builtinIsSupported - CHANGED
        Generate with body, Generate without body, Mark as updated
        isTSBuiltin - COMMENT
        Generate with body, Generate without body, Mark as updated
    ID - INCLUDE
    Generate with body, Generate without body, Mark as updated
```

```
--- /export/devarea/LLVM38/llvm/tools/clang/lib/Basic/Builtins.cpp
+++ /export/devarea/LLVM39/llvm/tools/clang/lib/Basic/Builtins.cpp
@@ -72,1 +72,3 @@
-   return !BuiltinsUnsupported && !MathBuiltinsUnsupported &&
+   bool OclCUnsupported = LangOpts.OpenCLVersion != 200 &&
+                          BuiltinInfo.Langs == OCLC20_LANG;
+   return !BuiltinsUnsupported && !MathBuiltinsUnsupported && !OclCUnsupported &&
```

Clank: Upgrade to Clang 3.9

- Tooling
  - Analyze diffs
  - Analyze dependencies
  - Detect Changed Entities
  - Prepare TODO actions
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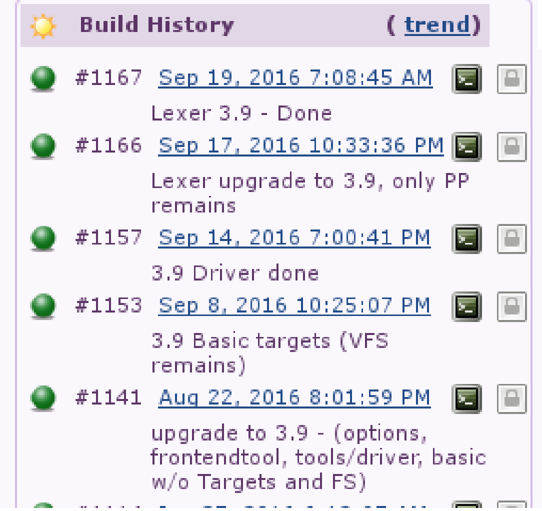
  - Mark progress
  - Track progress
- 1 person – 4 weeks for 1.1MLoc
- Improve Upgrade Tools based on feedback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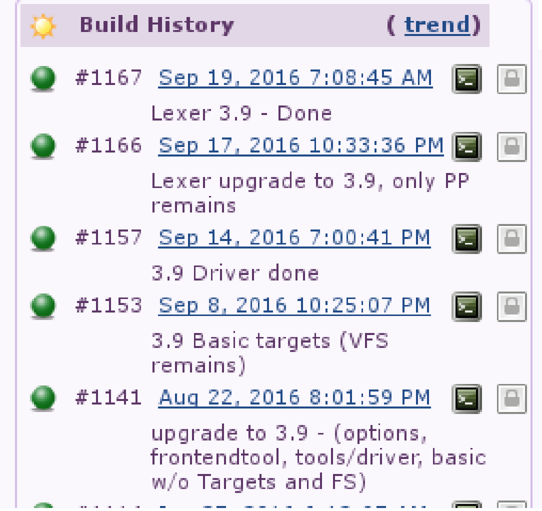

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Let's move toward complete C++ Frontend!

Agenda

- Why porting?
- Known approaches
- Converter
- Porting C++ and Clang challenges
- **Clank Demo**

Demo

Clank: Modular Structure

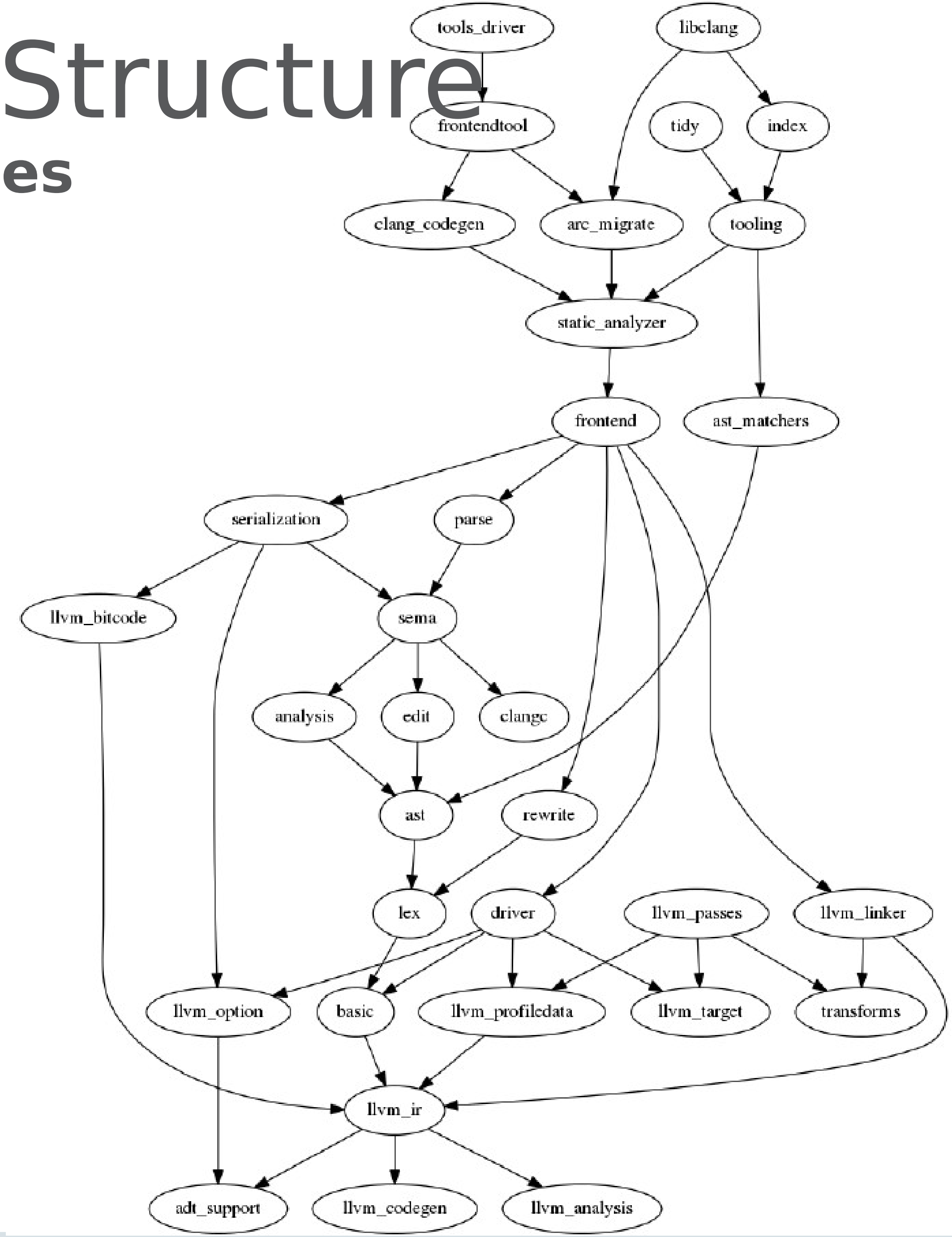
Java “LibC++”

- Memory and Pointers abstraction
- Unsigned types support
- Bit fields support
- STL Templates / Specializations
- I/O
- Function pointers
- @Converted annotation

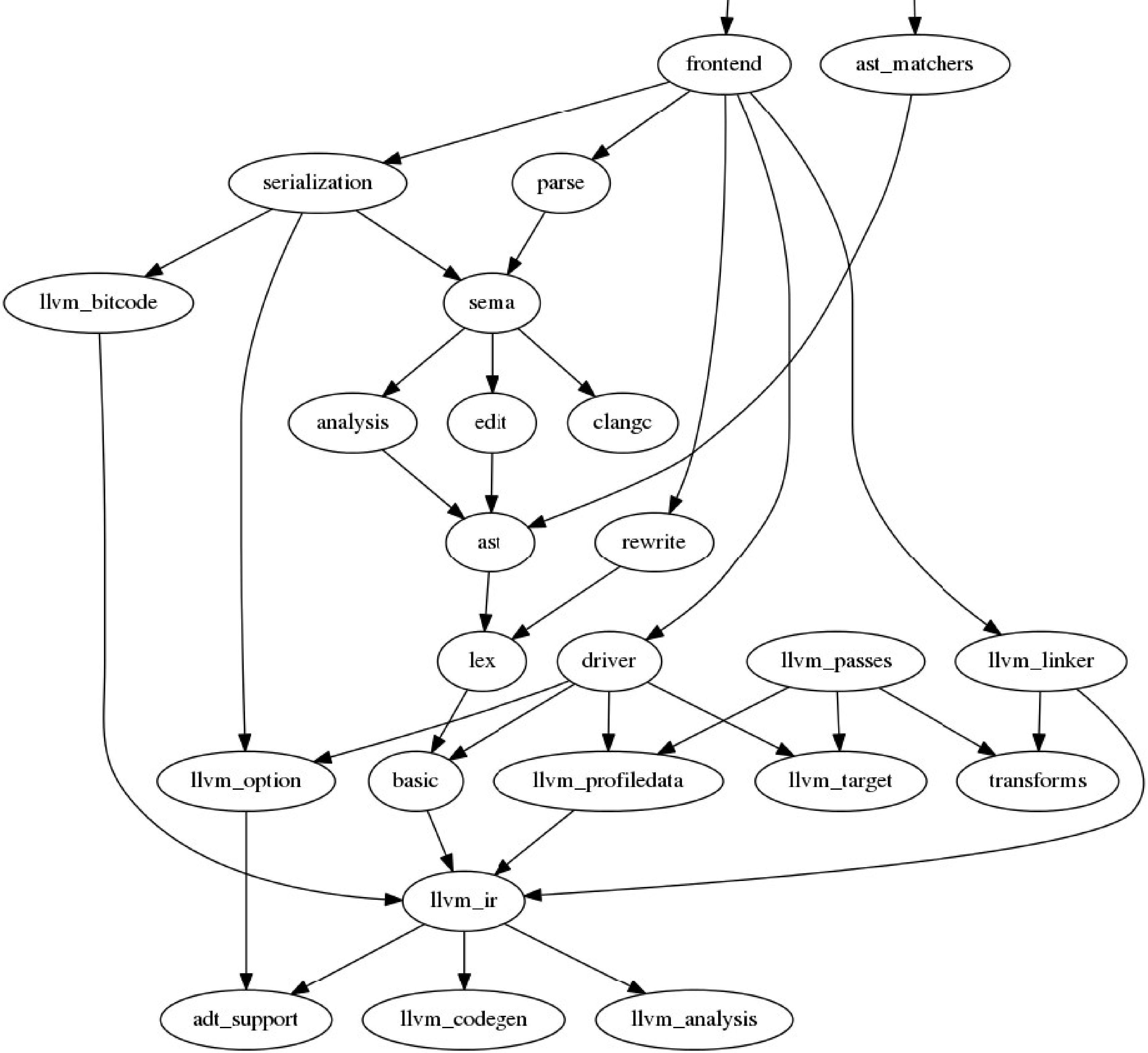
Clank: Modular Structure

Ported LLVM/Clang libraries

- Clang
  - Driver
  - Basic
  - Lex
  - AST
  - Analysis
  - Parse
  - Sema
  - Edit
  - Rewrite
  - Frontend
  - StaticAnalyzer
  - FrontendTool
  - Tools/Driver
- LLVM/Options
- ADT/Support On demand
  - with Templates and Specializations
- Tests: ADT/Support, Lexer, Preprocessor, Parser



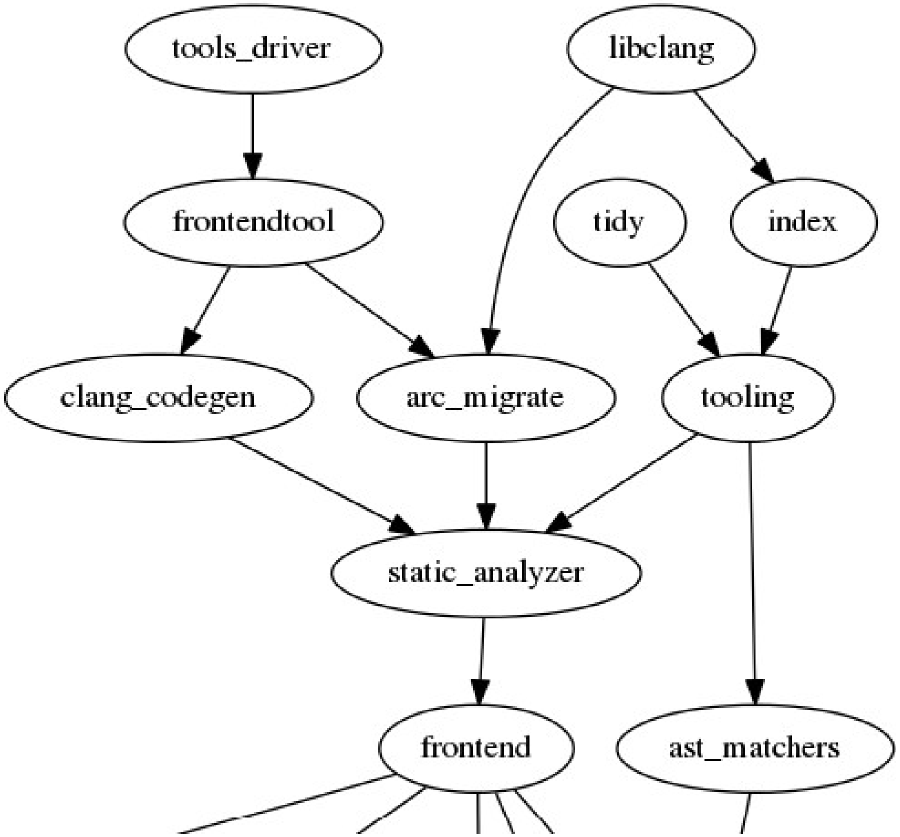
2 Million lines of code


frontend
ast_matchers
serialization
parse
llvm_bitcode
sema
analysis
edit
clangc
ast
rewrite
lex
driver
llvm_passes
llvm_linker
llvm_option
basic
llvm_profiledata
llvm_target
transforms
llvm_ir
adt_support
llvm_codegen
llvm_analysis

Clank: Modular Structure

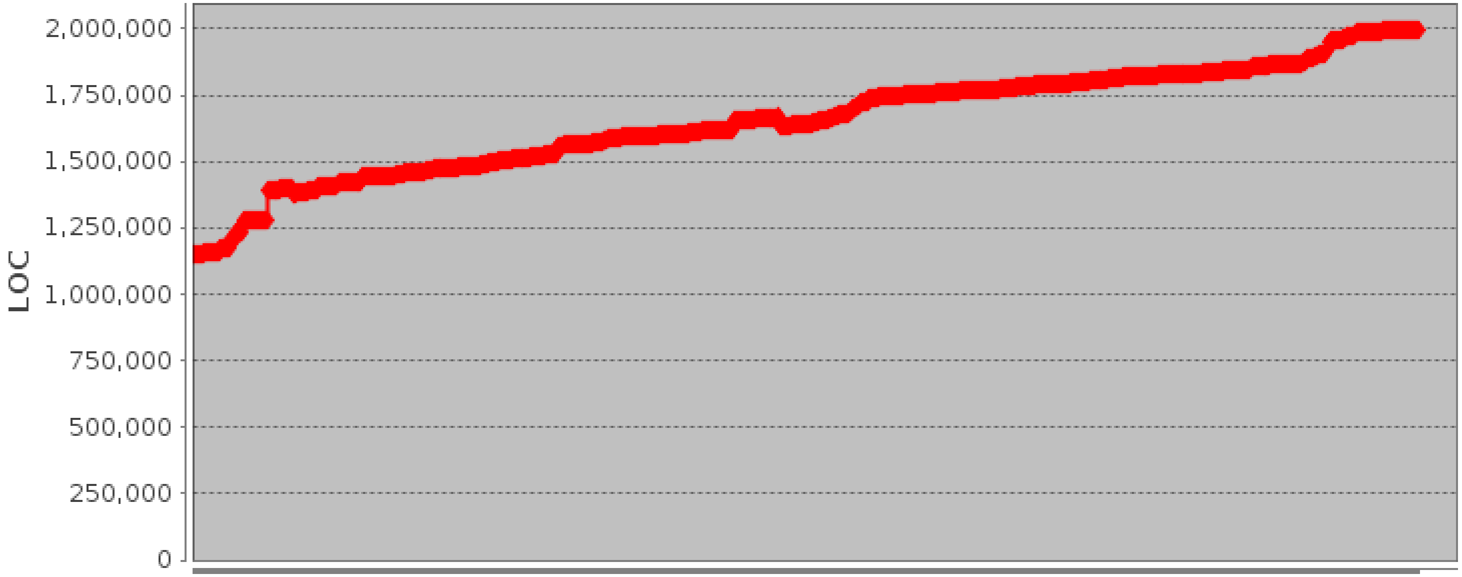
In-progress LLVM/Clang libraries

- Tooling
- ASTMatchers
- Serialization
- LLVM/Bitcode
- LLVM/IR



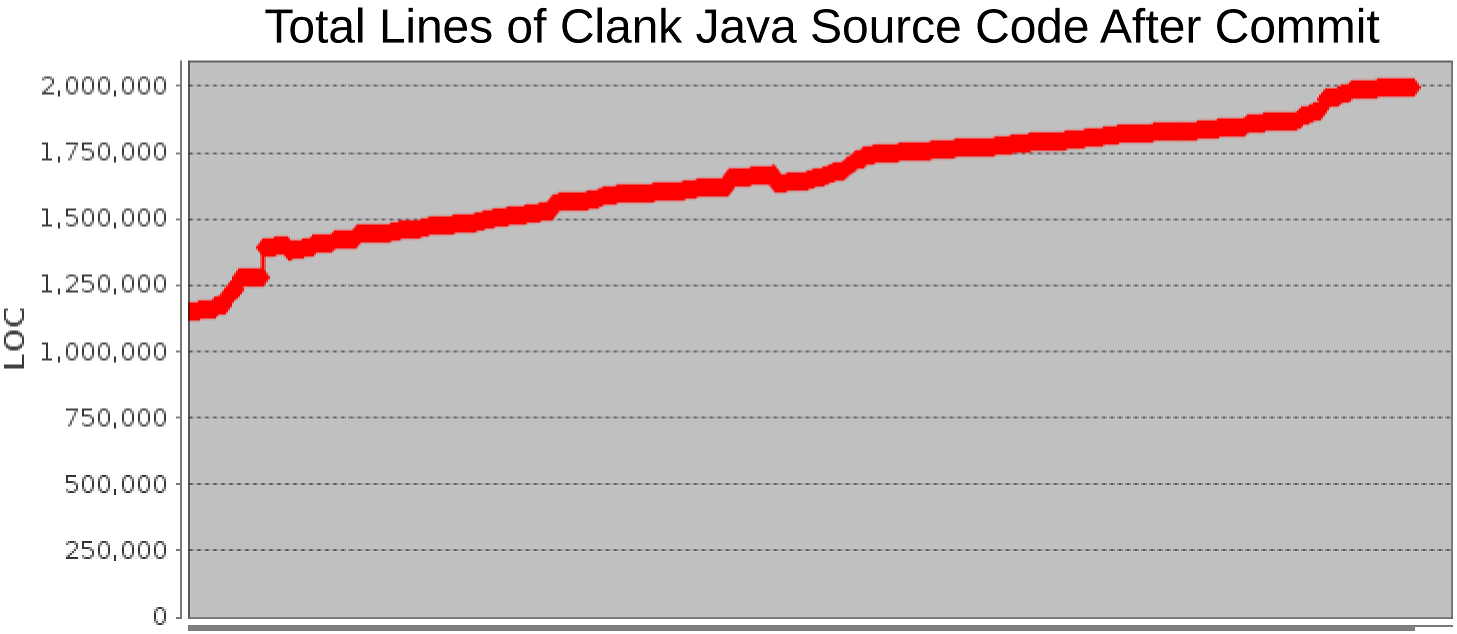
Clank: Porting progress

Total Lines of Clank Java Source Code After Commit



18 November 2016 ... 15 March 2017
2 persons: 4 months with long Russian NY break

Clank: Porting progress



18 November 2016 ... 15 March 2017
2 persons: 4 months with long Russian NY break

Improve Converter based on commits with
“MANUAL” keyword in subject
80% MANUALs are AUTO now

Clank

Thank you!

Clang

C++

Java™

Unite Developers Together