# Android Renderscript

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# Outline

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- Components
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- Java Reflection + rsForEach
- HelloCompute Example
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- Conclusions & Future Work

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# Renderscript Goals

- Develop a solution to providing a solid 60fps for our application frameworks
  - Has to work well with Dalvik
  - Has to work with existing hardware
  - Has to scale to future hardware without requiring developers to rewrite their applications
- Developed applications must be portable across a variety of hardware.  ARM v5, v7, NEON, x86, SSE, GPUs, DSPs
- Good performance across all devices instead of peak performance for one device at the expense of others
- Build a forward looking 3D graphics and compute API

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# Renderscript Design Principles

- Portability
  - Applications need to be able to run on a wide range of hardware without changes
  - Applications should be able take advantage of new instructions and processors without requiring a recompile or code changes
- Performance
  - Should be able to utilize advanced vector operations
  - Should be able to utilize non-CPU processors
- Usability
  - Within the above constraints what can we do to help developers?

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# Portability

To achieve portability, some code must be compiled on the device. This may happen either at install time, runtime, or possibly both.

- Leverage LLVM bitcode as our on-device portable format
- Generated by a Clang-based tool from C99 scripts running as part of the SDK build process

LLVM bitcode is not 100% portable

- Endian (we use little endian)
- Alignment (use size of type - i.e. 8-byte aligned double)
- sizeof(long) == 8 to match Java

# Performance

- Started with C99 due to its friendliness with compiling to a variety of HW targets and achieving good performance
- SMP primitives (forEach) built into the API
- Memory model designed to allow multiple memory spaces
  - Explicit sync points between memory spaces
  - Only script space is directly visible to the user
- Runtime is asynchronous with the application's Dalvik code
  - All communication goes through FIFOs
- Runtime is designed so the developer is not aware of which processor a given script is running on

# Usability

Our goal is to make this as easy to use for developers as possible:

- Portability and performance constraints
- Complicated HW-specific features such as local memory and thread launch types are deliberately **not** exposed
- We **don't** allow developers to control which processors their apps run on
  - This ties apps to specific HW
  - Creates forward portability problems
- Feature set is CPU like, not "mobile" GPU like.
  - Recursion, function pointers, full IEEE 754 fp32, fp64, ...

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# Renderscript Components

- Offline compiler (llvm-rs-cc)
  - Convert script files into portable bitcode and reflected Java layer
- Online JIT compiler (libbcc)
  - Translate portable bitcode to appropriate machine code (CPU/GPU/DSP/...)
- Runtime library support (librs)
  - Manage scripts from Dalvik layer
  - Also provide basic support libraries (graphics drawing functions, etc.)

# Offline Compiler: llvm-rs-cc

- Leverage Clang abstract syntax tree (AST) to reflect information and functionality back to Java layer
- Embeds metadata within bitcode (type, ...)
- Performs aggressive machine-independent optimizations on host before emitting portable bitcode
- All bitcode supplied as a resource within .apk container

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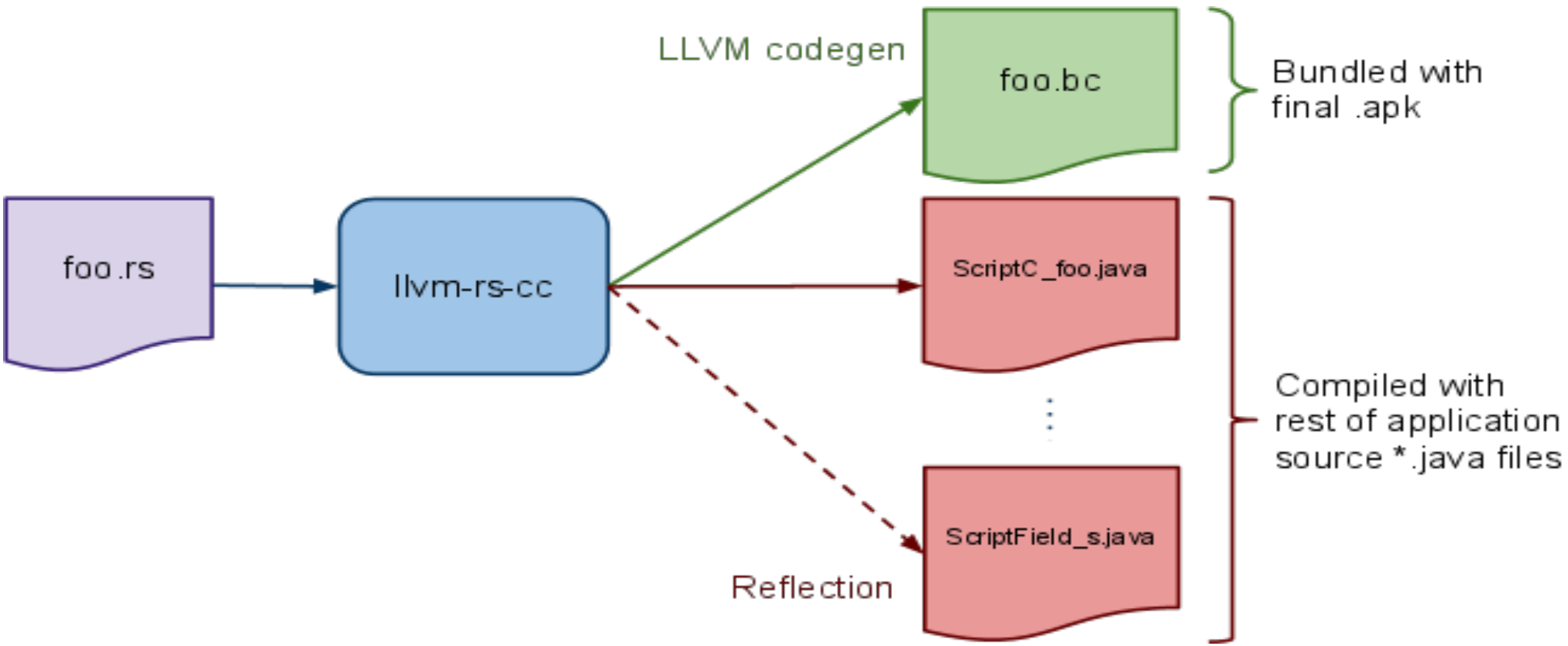
# Offline Compiler Flow

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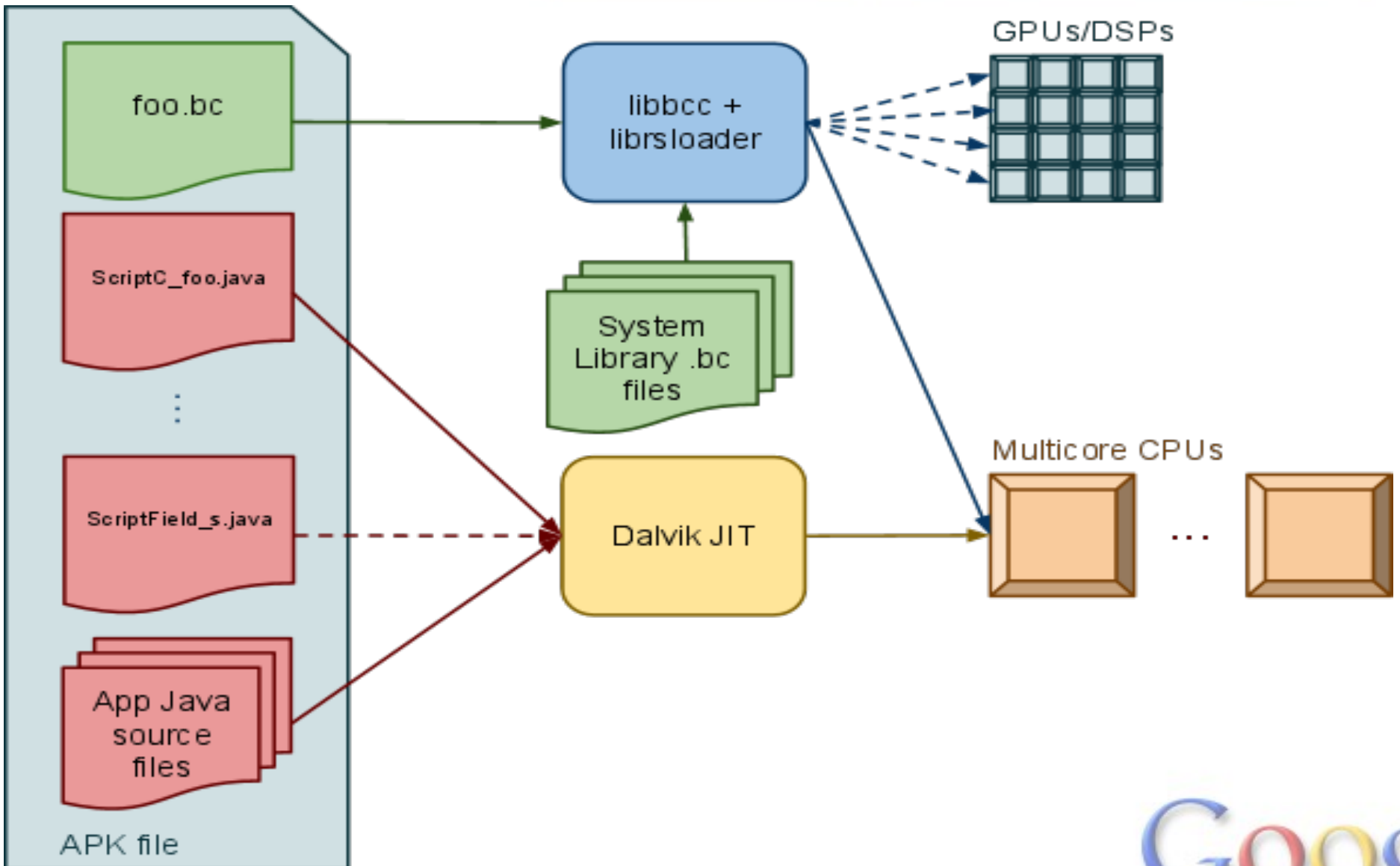
# Online JIT Compiler: libbcc

- Based on LLVM
  - Currently supports ARM and x86
  - Future targets include GPU/DSP
- Performs target-specific optimizations and code generation
- Provides hooks for runtime to access embedded metadata
- Links dynamically against runtime library functions (graphics, math)
- Caches JITted scripts to improve startup time
- Uses MC CodeGen to generate .o
- librsloader is used to load the .o file
- libbcinfo provides bitcode translator + metadata extraction

# Online JIT Compiler Flow

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# Renderscript Runtime: libRS

- Manages Scripts and other Renderscript objects
- Provides implementation of runtime libraries (math, time, drawing, ref-counting, ...)
- Allows allocation, binding of objects to Script globals
- Message-passing between control and runtime

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# Java Reflection

- Non-static global variables and functions are **automatically** reflected for use with Java app (control-side)
- Functions like `set_GlobalName()`
  - Set a runtime global to a new value
  - Not reflected for `const` variables
- Corresponding `get_GlobalName()`
  - Returns the most recently set control-side value
  - Starts out as initialized script-side value (zero-init is on by default because of C99)

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# Java Reflection (continued)

- Functions like **bind_GlobalPtr()**
  - Allows control side to bind Allocations to runtime global pointers
  - Implements call-by-reference (as opposed to **set()**'s call-by-value)
  - Pointer types also reflect **get()** functions appropriately (that return the most recently bound Allocation)
- Functions like **invoke_FuncName()**
  - Allows control side to execute a particular runtime function (complete with parameter passing)

# rsForEach

- Explicit parallelism (based on rs_allocation dimensions)
- Invokes root() function of script on each cell in allocation
  - **void root(const void *ain, void *aout,**
    **const void *usrData,**
    **uint32_t x, uint32_t y)**
- ICS - Reflect a Java helper to do parallel launch
  - **void forEach_root(Allocation ain,**
    **Allocation aout)**
- Need at least 1 of input/output allocation (determines launch dimensions)
- ICS - Improved type and dimensionality verification in reflected Java helper

# rsForEach (continued)

- Also available in rs_core.rsh to the C99-based scripts:

```
extern void __attribute__((overloadable))
    rsForEach(rs_script script,
              rs_allocation input,
              rs_allocation output,
              const void * usrData,
              size_t usrDataLen);

extern void __attribute__((overloadable))
    rsForEach(rs_script script,
              rs_allocation input,
              rs_allocation output,
              const void * usrData,
              size_t usrDataLen,
              const rs_script_call_t *);
```

# HelloCompute Example

- Available in Android SDK samples
- Converts a bitmap image to grayscale
- Exploits parallelism by using rsForEach on every pixel of an allocation (simple dot product of RGB values)
- mono.rs -> mono.bc + reflected to ScriptC_mono.java

# Sample Script (mono.rs)

```
#pragma version(1)
#pragma rs java_package_name(com.example.android.rs.hellocompute)

const static float3 gMonoMult = {0.299f, 0.587f, 0.114f};

void root(const uchar4 *v_in, uchar4 *v_out, uint32_t x, uint32_t y) {
   float4 f4 = rsUnpackColor8888(*v_in);

   float3 mono = dot(f4.rgb, gMonoMult);
   *v_out = rsPackColorTo8888(mono);
}
```

# ScriptC_mono.java (generated pt. 1)

```
package com.example.android.rs.hellocompute;

import android.renderscript.*;
import android.content.res.Resources;

public class ScriptC_mono extends ScriptC {
    // Constructor
    public ScriptC_mono(RenderScript rs, Resources resources, int id) {
        super(rs, resources, id);
        __U8_4 = Element.U8_4(rs);
    }

    private Element __U8_4;
    private final static int mExportForEachIdx_root = 0;
    public void forEach_root(Allocation ain, Allocation aout) {
        // check ain
        if (!ain.getType().getElement().isCompatible(__U8_4)) {
            throw new RSRuntimeException("Type mismatch with U8_4!");
        }
...
```

# ScriptC_mono.java (generated pt. 2)

```
...
        // check aout
        if (!aout.getType().getElement().isCompatible(__U8_4)) {
            throw new RSRuntimeException("Type mismatch with U8_4!");
        }
        // Verify dimensions
        Type tIn = ain.getType();
        Type tOut = aout.getType();
        if ((tIn.getCount() != tOut.getCount()) ||
            (tIn.getX() != tOut.getX()) ||
            (tIn.getY() != tOut.getY()) ||
            (tIn.getZ() != tOut.getZ()) ||
            (tIn.hasFaces() != tOut.hasFaces()) ||
            (tIn.hasMipmaps() != tOut.hasMipmaps())) {
            throw new RSRuntimeException("Dimension mismatch between input and output parameters!");
        }
        forEach(mExportForEachIdx_root, ain, aout, null);
    }
}
```

# HelloCompute.java (partial source)

```
public class HelloCompute extends Activity {
    ...
    private void createScript() {
        mRS = RenderScript.create(this);

        mInAllocation = Allocation.createFromBitmap(mRS, mBitmapIn,
            Allocation.MipmapControl.MIPMAP_NONE,
            Allocation.USAGE_SCRIPT);
        mOutAllocation = Allocation.createTyped(mRS,
            mInAllocation.getType());

        mScript = new ScriptC_mono(mRS, getResources(), R.raw.mono);

        mScript.forEach_root(mInAllocation, mOutAllocation);
        mOutAllocation.copyTo(mBitmapOut);
    }
    ...
}
```

# LLVM Challenges

- Bitcode versioning
  - Honeycomb
    - Only supported legacy JIT path
    - LLVM 2.7 - 2.9 bitcode depending on MR version
  - Ice Cream Sandwich
    - MC CodeGen
    - LLVM 3.0 bitcode - this one will last a while, right? ;)
  - Solution - provide a translator to go between versions
    - Partners only need to support latest bitcode format
    - llvm-rs-cc generates older bitcode for older target API
- Metadata extraction
  - Don't force partners rewrite this for every target backend + RS driver implementation

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# Source Differences

- android/external/clang
  - 32 line diff from Clang upstream!
    - Support for RGBA vector selection (28 lines)
    - Support flag to force "long" to 64-bit (4 lines)
    - Ready to upstream now
- android/external/llvm
  - 368 line diff from LLVM upstream!
  - Mostly patches for legacy JIT path (no longer used - essentially dead code)
  - Stripped down a bit to fit on current tablet/smartphone
  - No debugging support currently (since we don't emit DWARF from llvm-rs-cc today)

# Adventures in AST Annotation

- Renderscript runtime manages a bunch of types
  - Allocations in the sample script (plus other things too)
  - How do we know when they can be cleaned up?
    - Java-Side ???
    - Script-Side ???
- Reference Counting
  - rsSetObject(), rsClearObject()
  - Developers do not want to micro-manage opaque blobs
  - Solution is to dynamically annotate script code to use these functions in the appropriate spots

# Annotating the AST

- Update this in-place before we emit bitcode
- Need to do a few types of conversions on variables with an RS object type (rs_* types, not including rs_matrix*)
  - Assignments -> rsSetObject(&lhs, rhs)
  - Insert destructor calls as rsClearObject(&local) for locals
- Global variables get cleaned up by runtime after script object is destroyed

# Reference Counting Example

```
rs_font globalIn[10], globalOut;
void foo(int j) {
  rs_font localUninit;
  localUninit = globalIn[0];

  for (int i = 0; i < j; i++) {
    rs_font forNest = globalIn[i];

    switch (i) {
      case 3:


        return;
      case 7:

        continue;
      default:
        break;
    }
    localUninit = forNest;

  }

  globalOut = localUninit;

  return;
}
```

# RS Object Local Variables

```
rs_font globalIn[10], globalOut;
void foo(int j) {
  rs_font localUninit;
  localUninit = globalIn[0];

  for (int i = 0; i < j; i++) {
    rs_font forNest = globalIn[i];

    switch (i) {
      case 3:


        return;
      case 7:

        continue;
      default:
        break;
    }
    localUninit = forNest;

  }

  globalOut = localUninit;

  return;
}
```

# Assignment -> rsSetObject()

```
rs_font globalIn[10], globalOut;
void foo(int j) {
  rs_font localUninit;
  rsSetObject(&localUninit, globalIn[0]);    // Simple translation to call-expr

  for (int i = 0; i < j; i++) {
    rs_font forNest;
    rsSetObject(&forNest, globalIn[i]);      // Initializers must be split before conversion
    switch (i) {
      case 3:


        return;
      case 7:

        continue;
      default:
        break;
    }
    rsSetObject(&localUninit, forNest);

  }

  rsSetObject(&globalOut, localUninit);

  return;
}
```

# Insert Destructor Calls

```
rs_font globalIn[10], globalOut;
void foo(int j) {
  rs_font localUninit;
  rsSetObject(&localUninit, globalIn[0]);

  for (int i = 0; i < j; i++) {
    rs_font forNest;
    rsSetObject(&forNest, globalIn[i]);
    switch (i) {
      case 3:
        rsClearObject(&localUninit);      // Return statements always require that you
        rsClearObject(&forNest);          // destroy any in-scope local objects (inside-out).
        return;
      case 7:
        rsClearObject(&forNest);          // continue scopes to for-loop, so destroy forNest
        continue;
      default:
        break;                        // break scopes to switch-stmt, so do nothing
    }
    rsSetObject(&localUninit, forNest);
    rsClearObject(&forNest);              // End of for-loop scope, so destroy forNest
  }

  rsSetObject(&globalOut, localUninit);
  rsClearObject(&localUninit);            // End outer scope (before return)
  return;
}
```

# Conclusions

- Renderscript
  - Portable, high-performance, and developer-friendly
  - 3D graphics + compute acceleration path
- Hide complexity through compiler + runtime
  - C99-based + forEach
  - Ample use of reflection
  - Library functions
  - Opaque managed types + reference counting
- Future Work
  - Debugging and profiling support
  - Improved use of vector intrinsics
- See http://developer.android.com/ for the latest info

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