TIL (Things I Learned)
Performance Analysis of CoreCLR Interpreter

Yuchong Pan

Microsoft

August 6, 2020

TIL: What's TIL?

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- TIL = **T**oday **I** **L**earned

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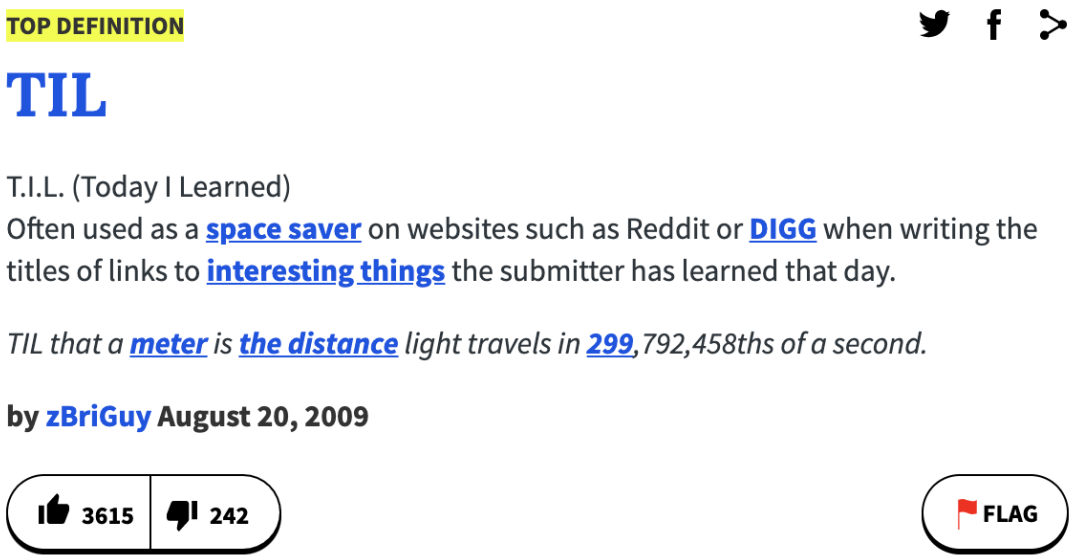

TOP DEFINITION

TIL

T.I.L. (Today I Learned)
Often used as a **space saver** on websites such as Reddit or **DIGG** when writing the titles of links to **interesting things** the submitter has learned that day.

*TIL that a **meter** is **the distance** light travels in **299**,792,458ths of a second.*

by zBriGuy August 20, 2009

3615 242

FLAG

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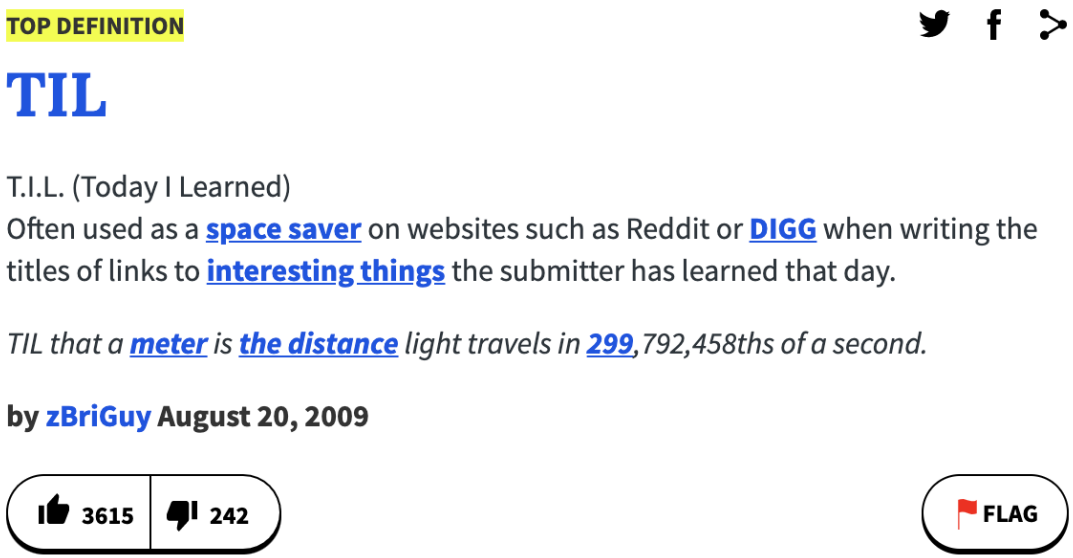

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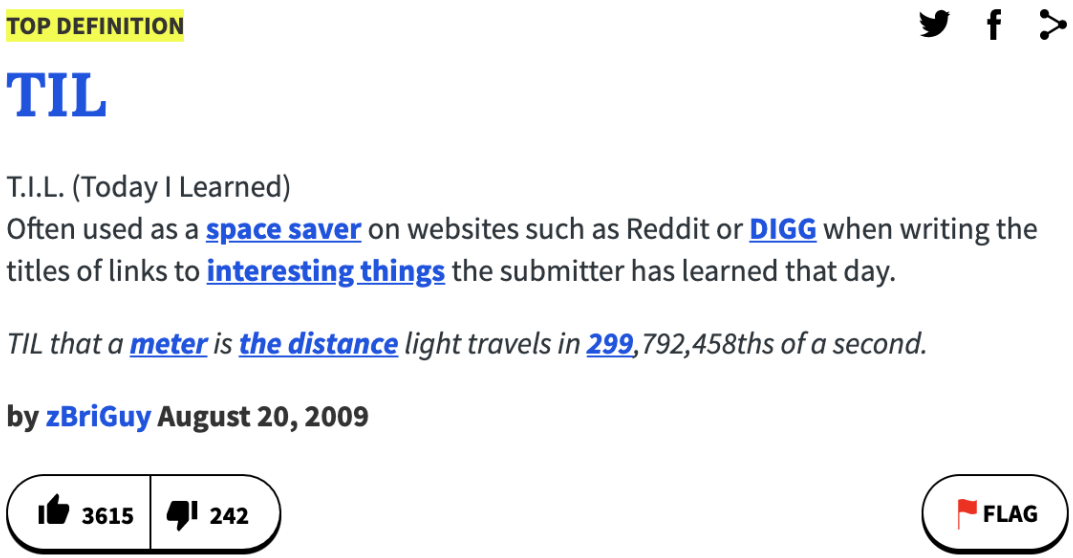

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- TIL = **T**hings **I** **L**earned about the CoreCLR interpreter and its performance during my internship in the summer of 2020

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- Last year: .NET Core Uninstall Tool

.NET Core Uninstall Tool

05/27/2020 • 11 minutes to read •

The .NET Core Uninstall Tool (`dotnet-core-uninstall`) lets you remove .NET Core SDKs and Runtimes from a system. A collection of options is available to specify which versions you want to uninstall.

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TIL: Why Is the Interpreter So Interesting?

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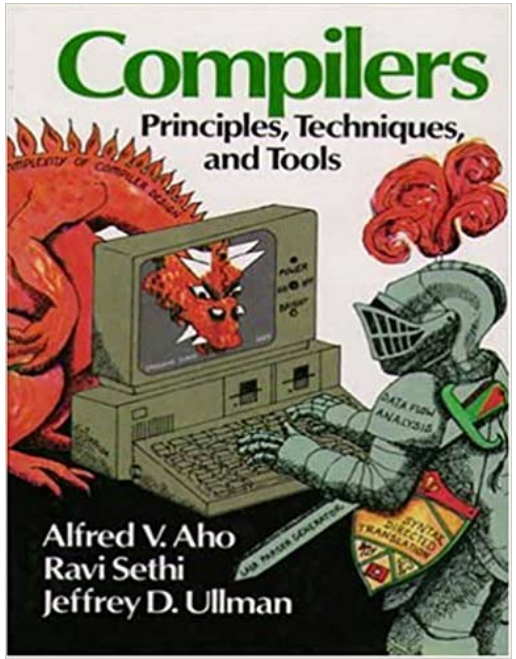
- In a typical, traditional undergraduate compiler course, each method in your program is compiled **once**.



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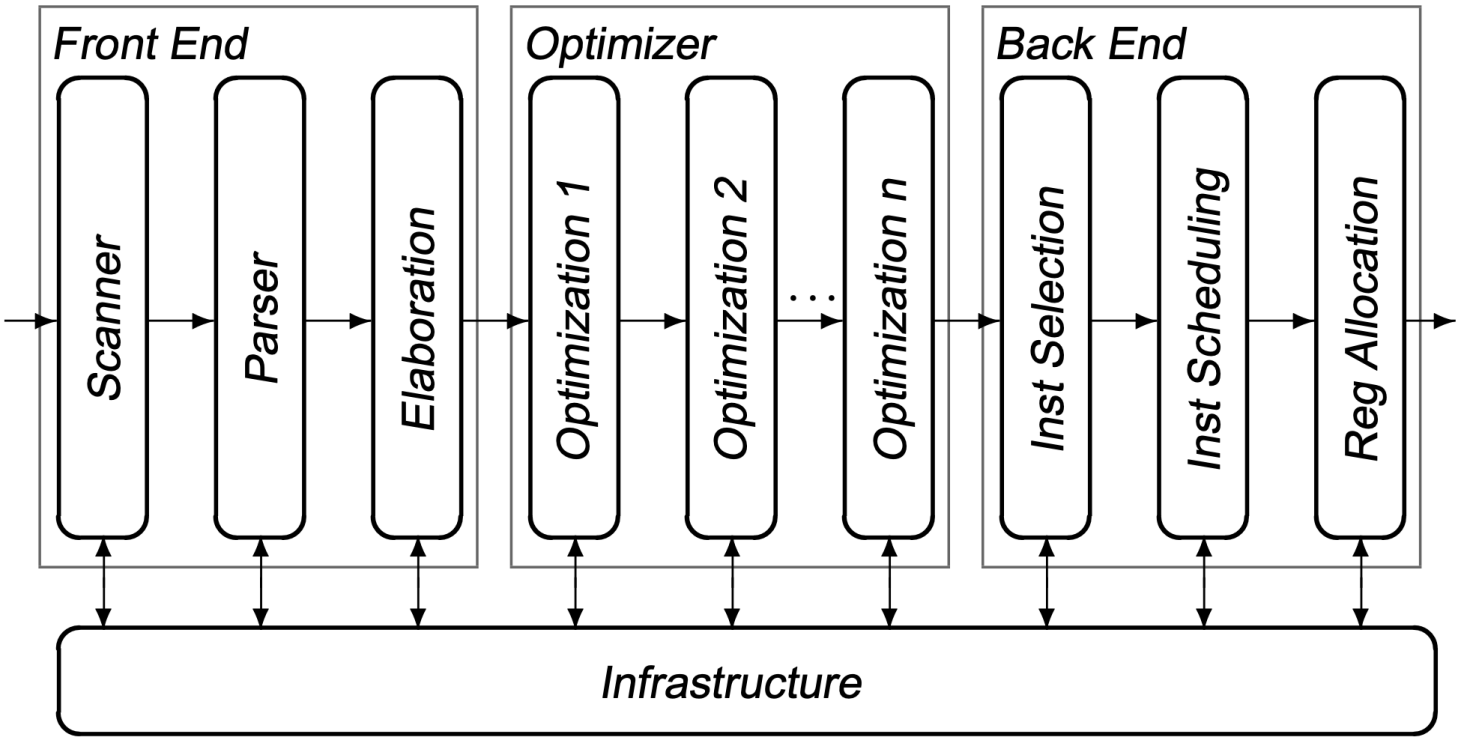

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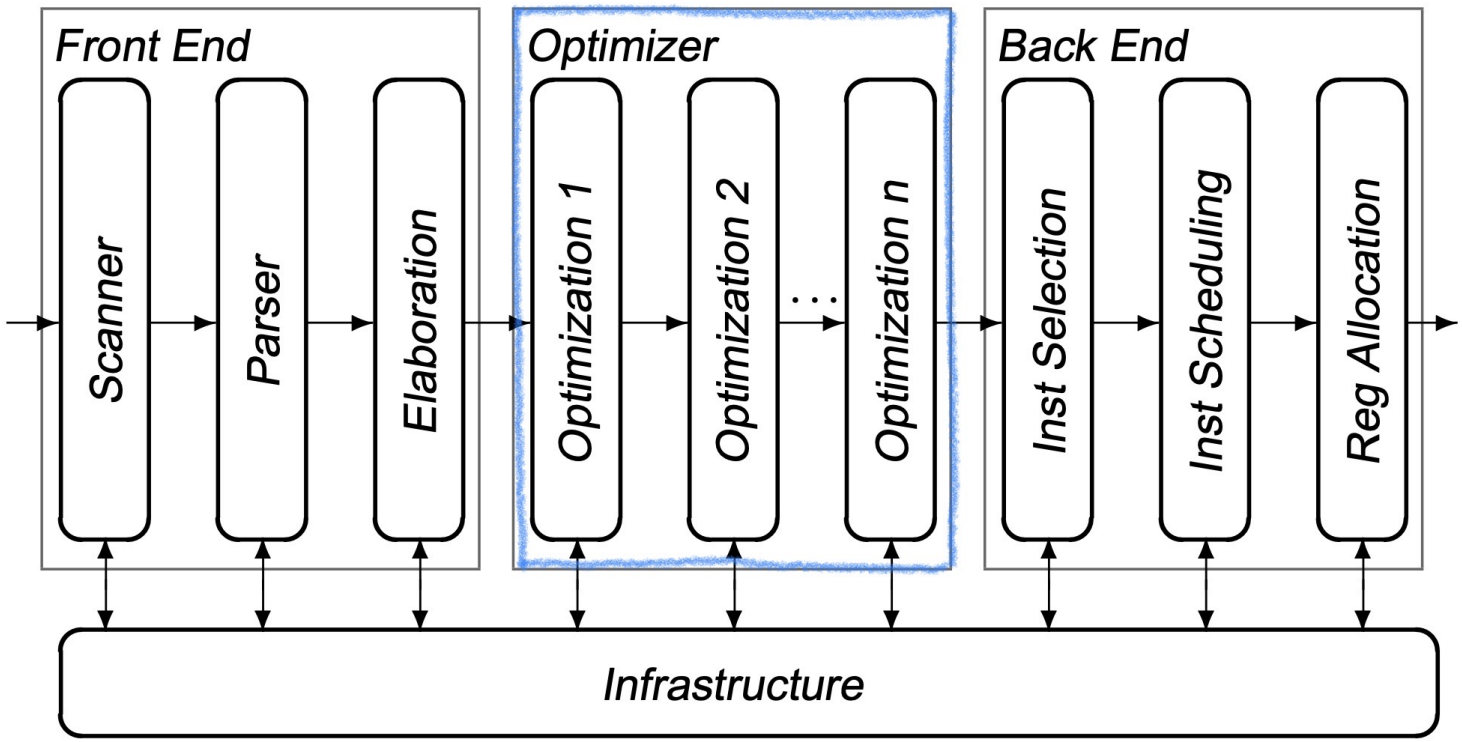

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- Alternatively, **less** optimization means **faster** start-up time but **slower** steady-state performance.

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- **Faster steady-state performance:** If a method is called frequently, more optimized code is generated **asynchronously**, which then replaces the initial code. **(Tier 1)**
- **ReadyToRun** images have several constraints which prohibit some types of optimization. TC generates optimized code that replaces the pre-compiled version.

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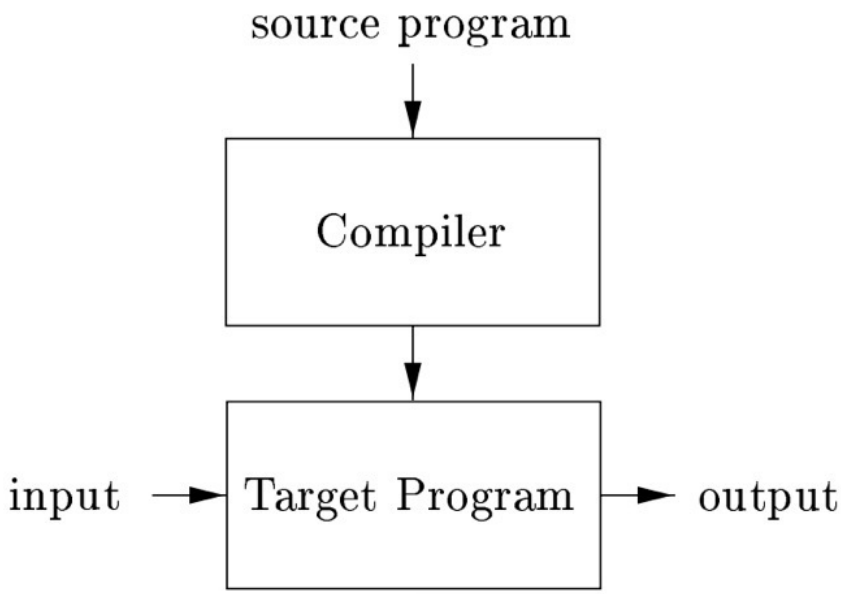

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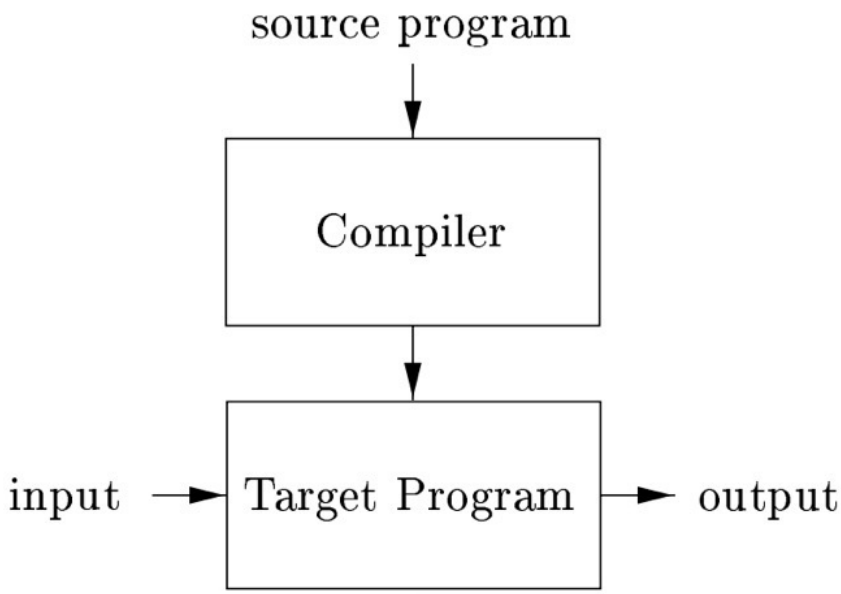

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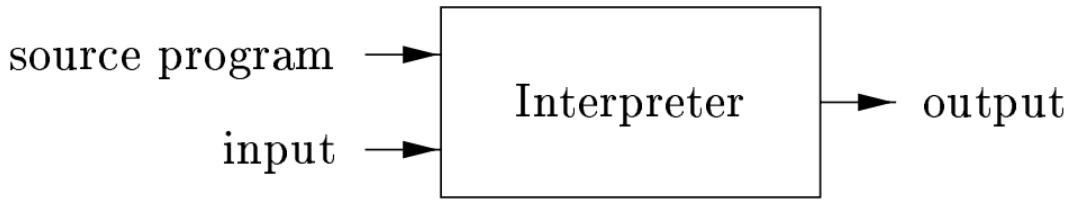

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Conjecture

Replacing the current Tier 0 JIT with an interpreter in Tiered Compilation would achieve faster start-up time, while preserving the fast steady-state performance from the Tier 1 JIT, and not deteriorating the total execution time by too much.

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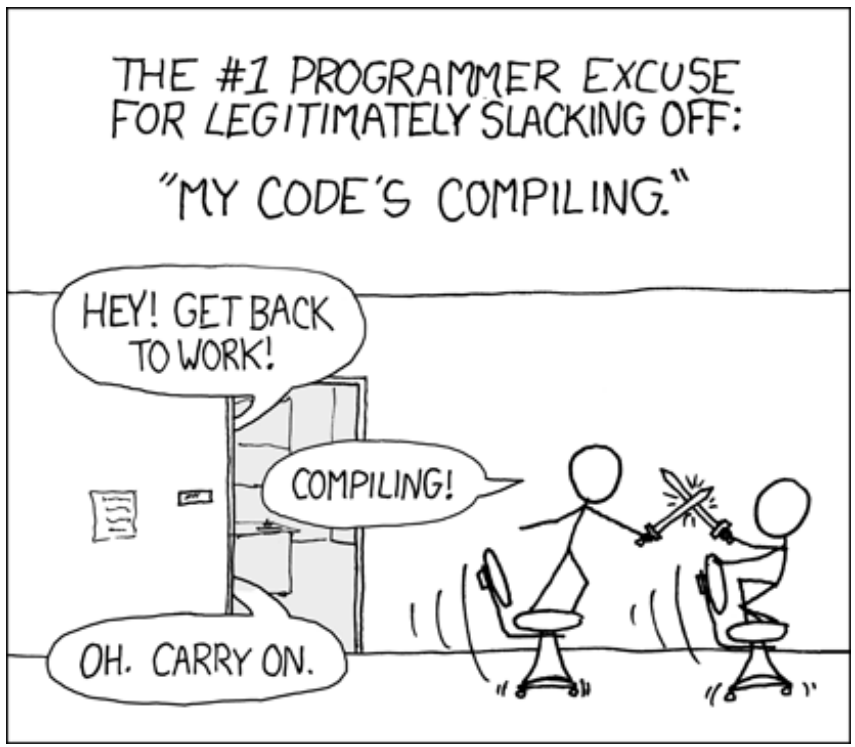

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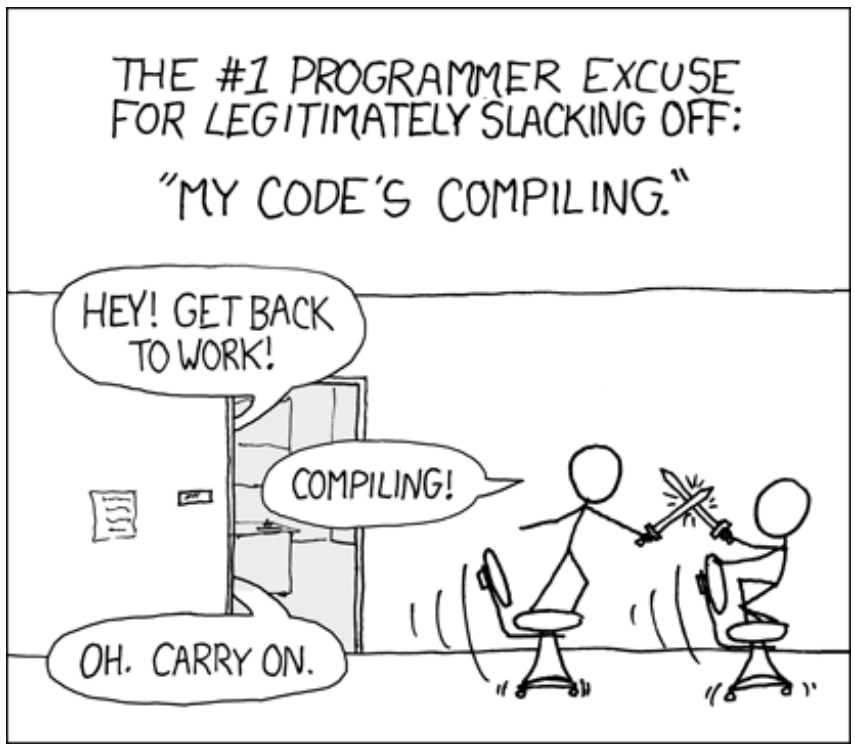

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```
static bool Not(bool p)
{
    bool q = p;
    q = !q;
    return q;
}

static void Main(string[] args)
{
    Console.WriteLine("Hello World!");
    bool b = true;
    bool bb = Not(b);

    bb = Not(bb);
    // ... 30 additional lines of `bb = Not(bb);`

    Console.WriteLine(bb);
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- The number of calls to `Not` is used to trigger the promotion to Tier 1 in Tiered Compilation.

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{
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- **Priority 0 tests:**
  Total: 2822
  Failed: 184
  Passing Percentage: 93.48%

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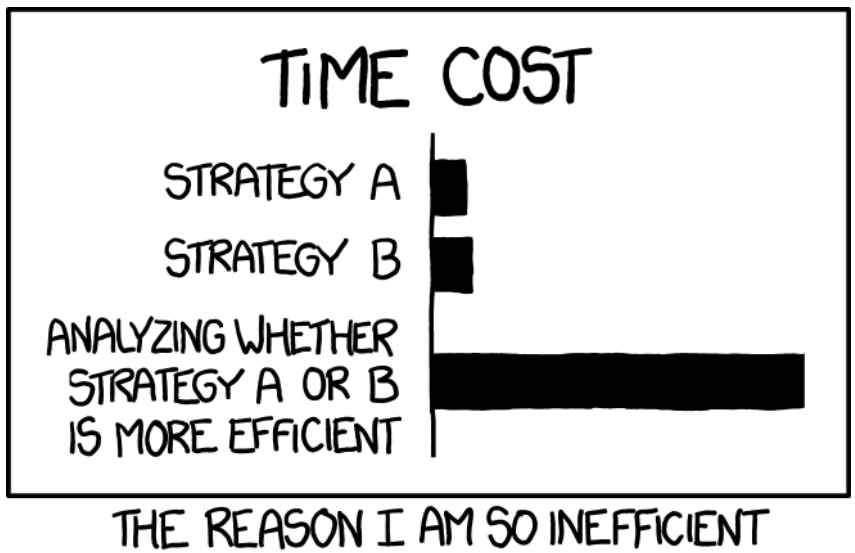

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- **Question #1:** How much is the interpreter slower than the Tier 0 and Tier 1 JIT, respectively?

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Replacing the current Tier 0 JIT with an interpreter in Tiered Compilation would achieve faster start-up time, while preserving the fast steady-state performance from the Tier 1 JIT, and not deteriorating the total execution time by too much.

- **Steady-state performance:** `SciMark 2.0` with `BenchmarkDotNet`, including benchmarks of scientific and numerical computing, e.g. Fast Fourier Transform (FFT), Successive Over-Relaxation (SOR), Monte Carlo Integration, Sparse Matrix Multiply, and LU Matrix Factorization.
- **Question #1:** How much is the interpreter slower than the Tier 0 and Tier 1 JIT, respectively?
- **Question #2:** Is the steady-state performance after several warm-up iterations close to the Tier 1 JIT performance?

TIL from Beautiful Plots

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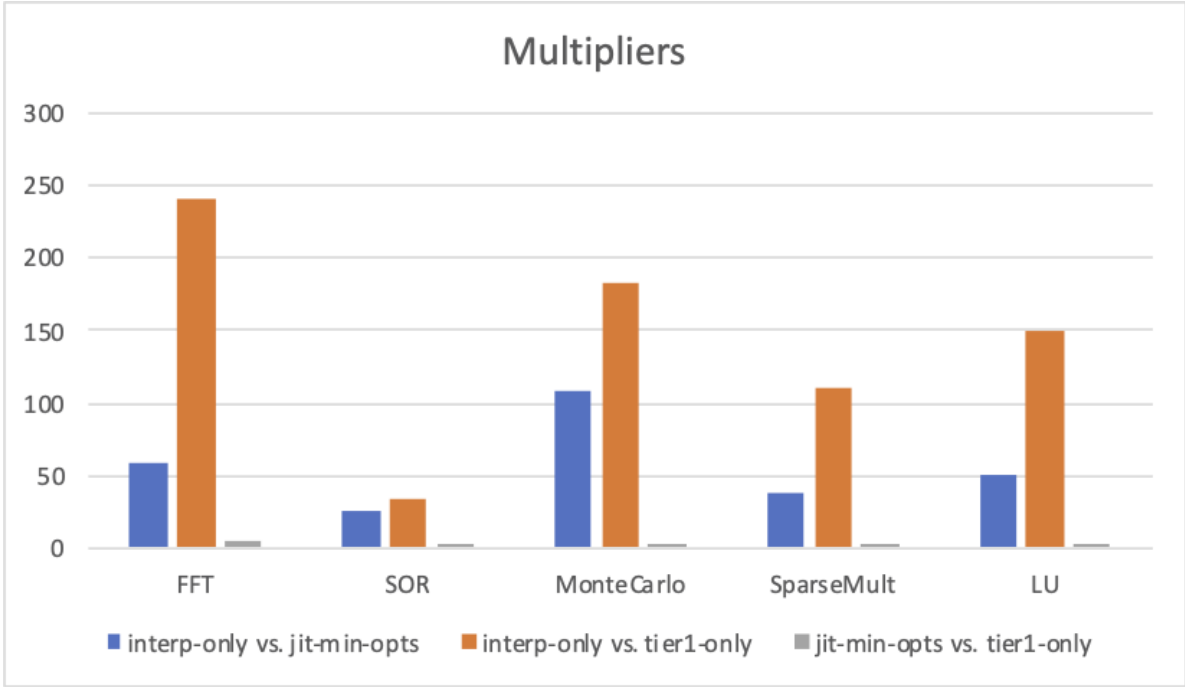

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The multipliers with a **Checked** build is between 333–2306 compared to `jit-min-opts`, and between 441–3937 compared to `tier1-only`, much greater than a **Release** build.

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Conjecture

The interpretation of IL code is the execution of native C++ code. A **Release** build disables many assertions and enables many optimizations of the native code.

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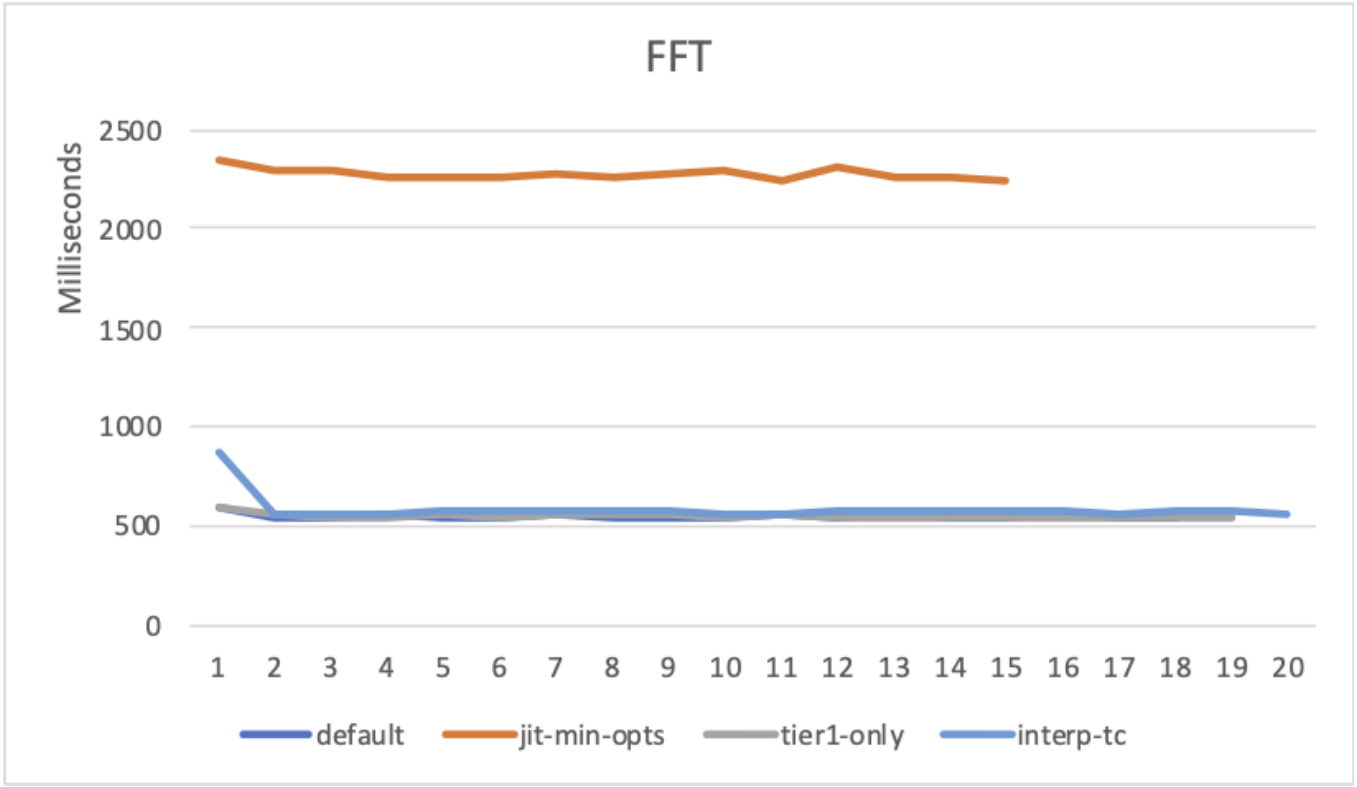

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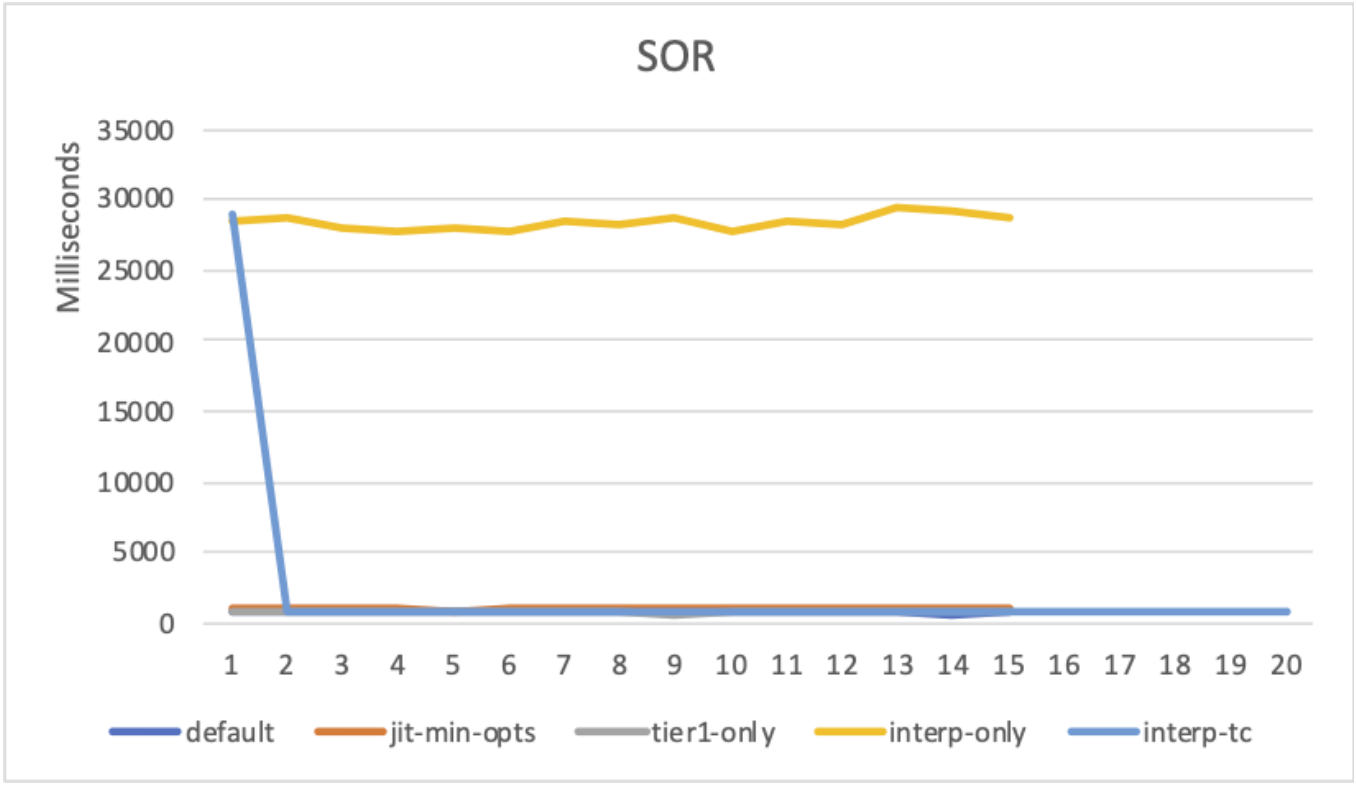

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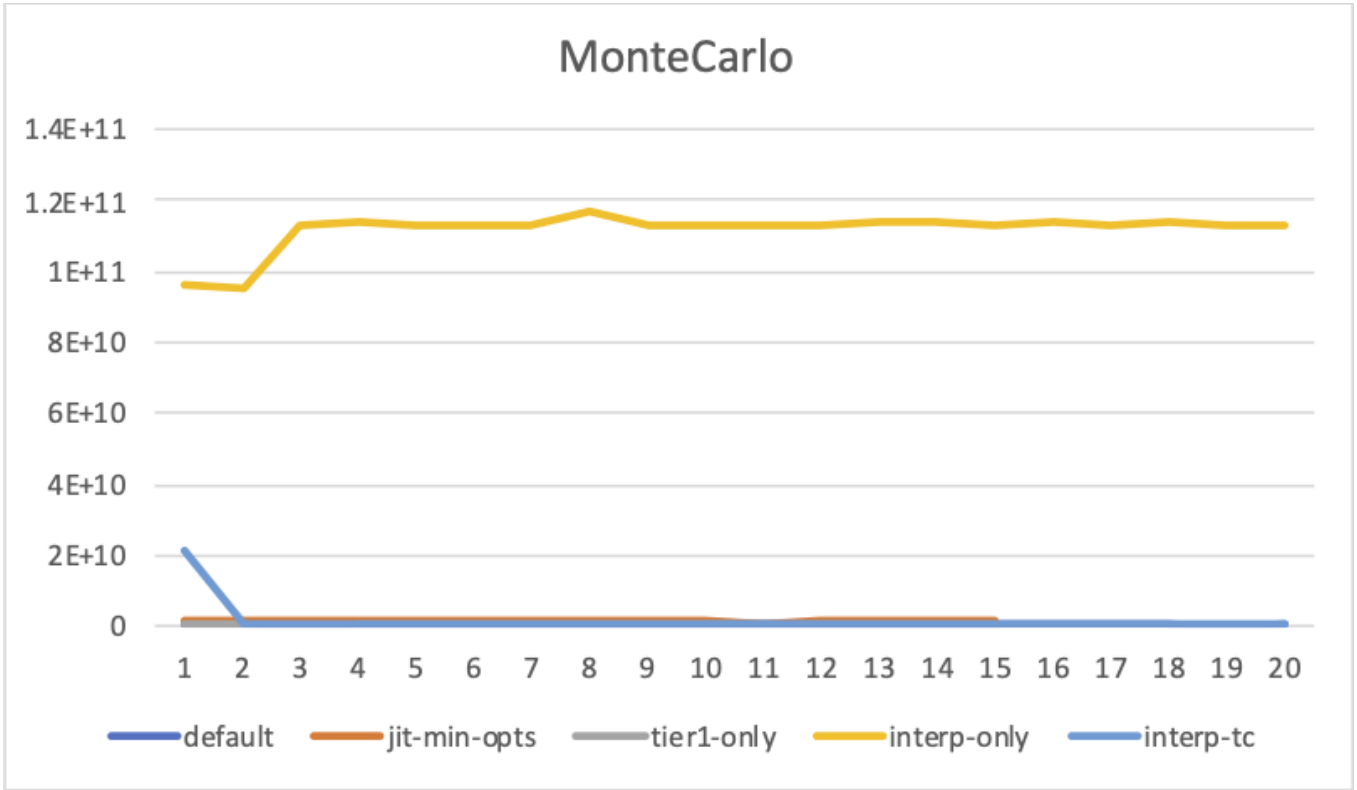

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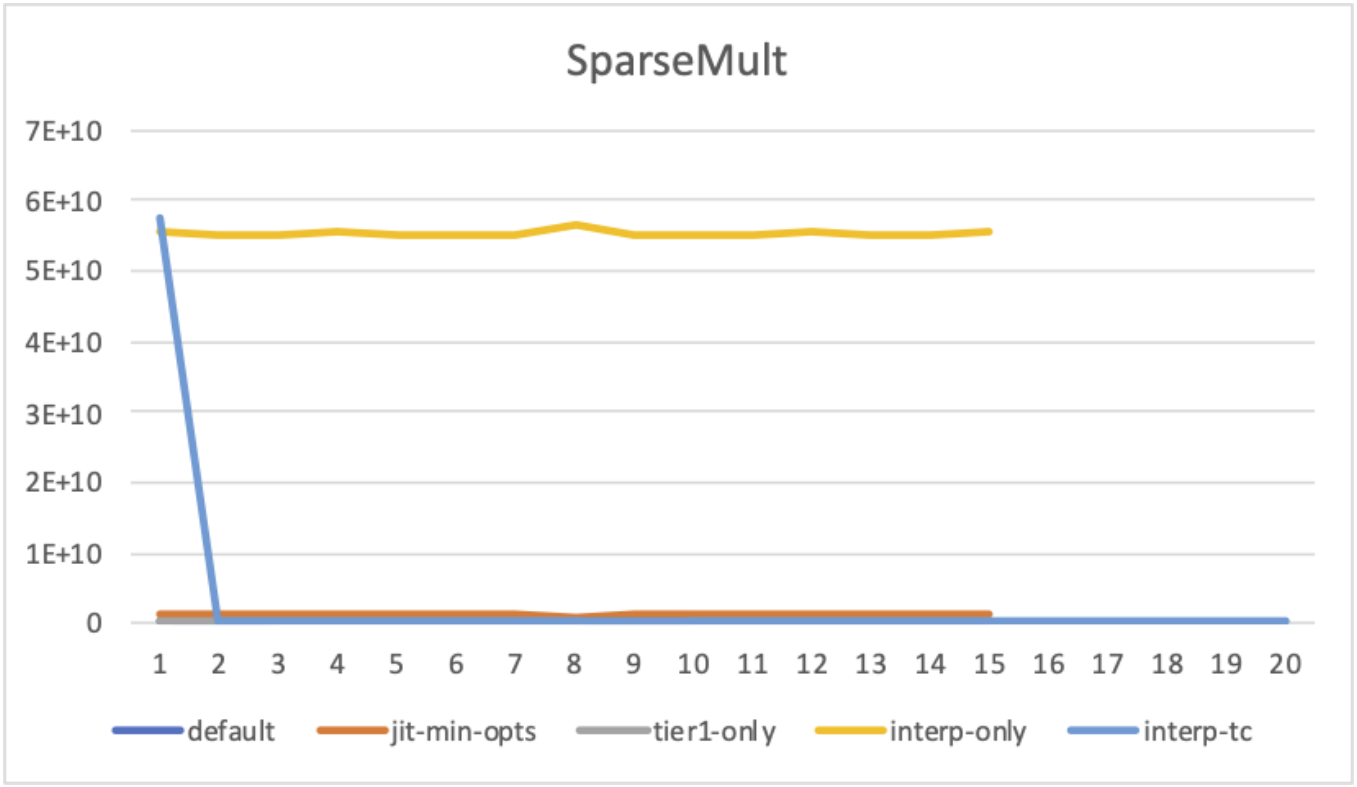

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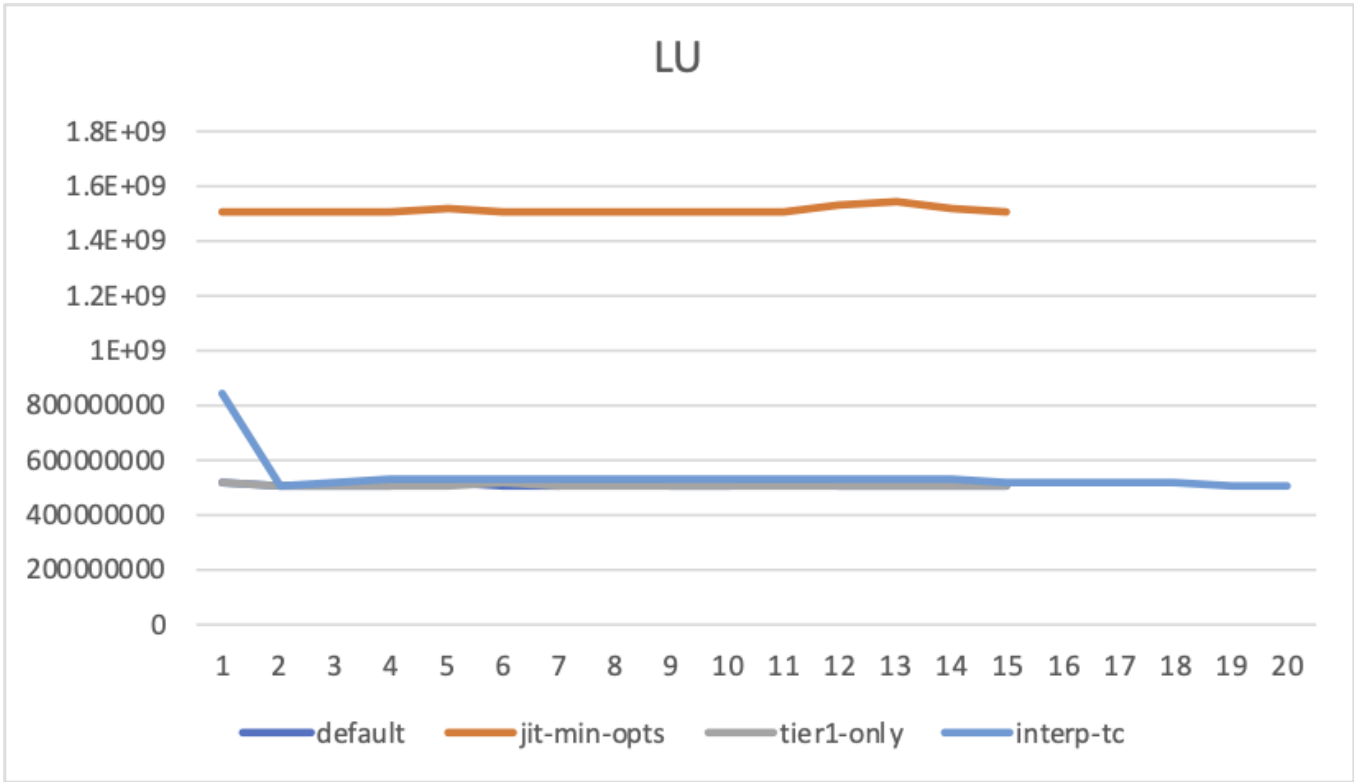

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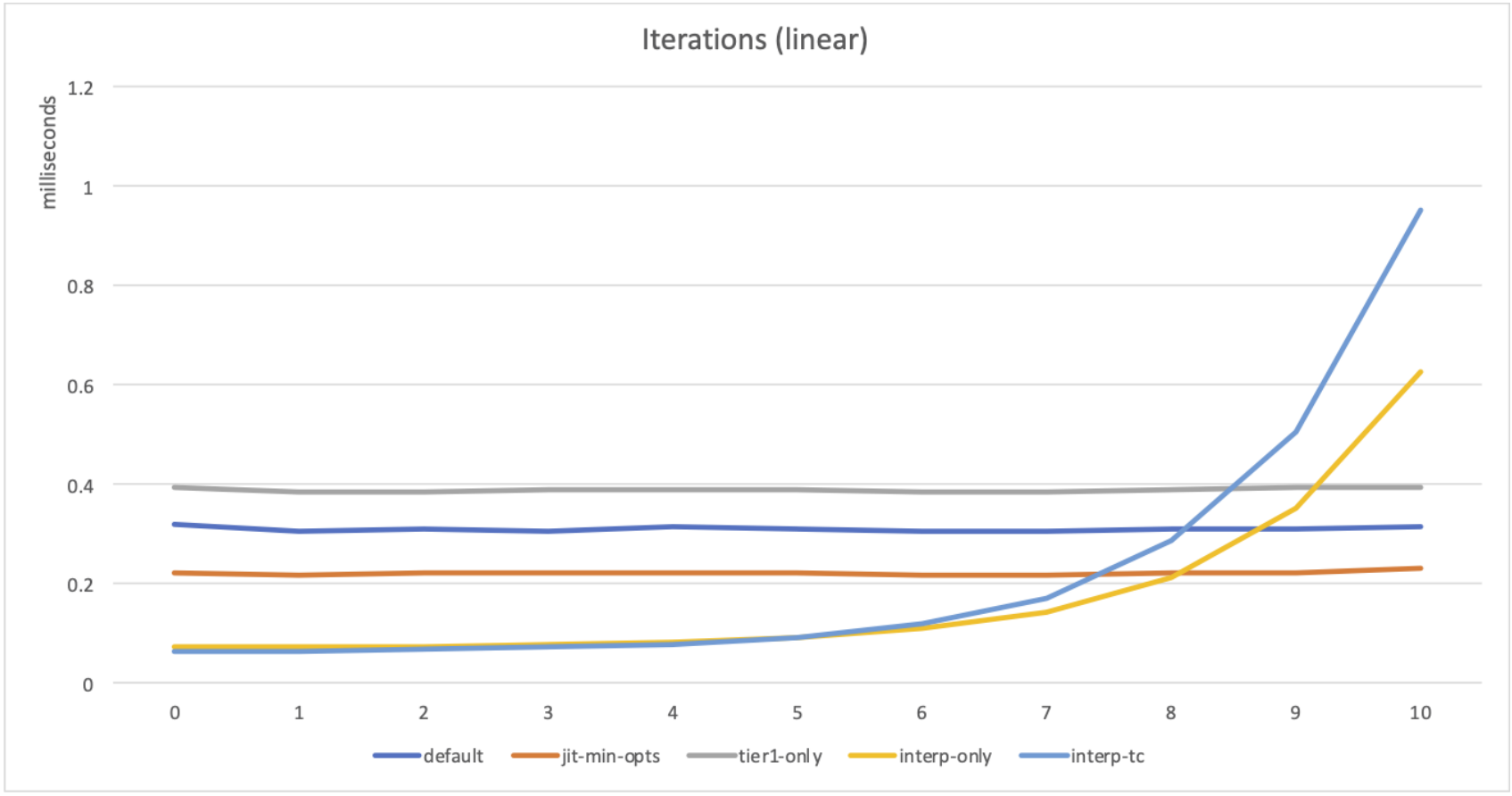

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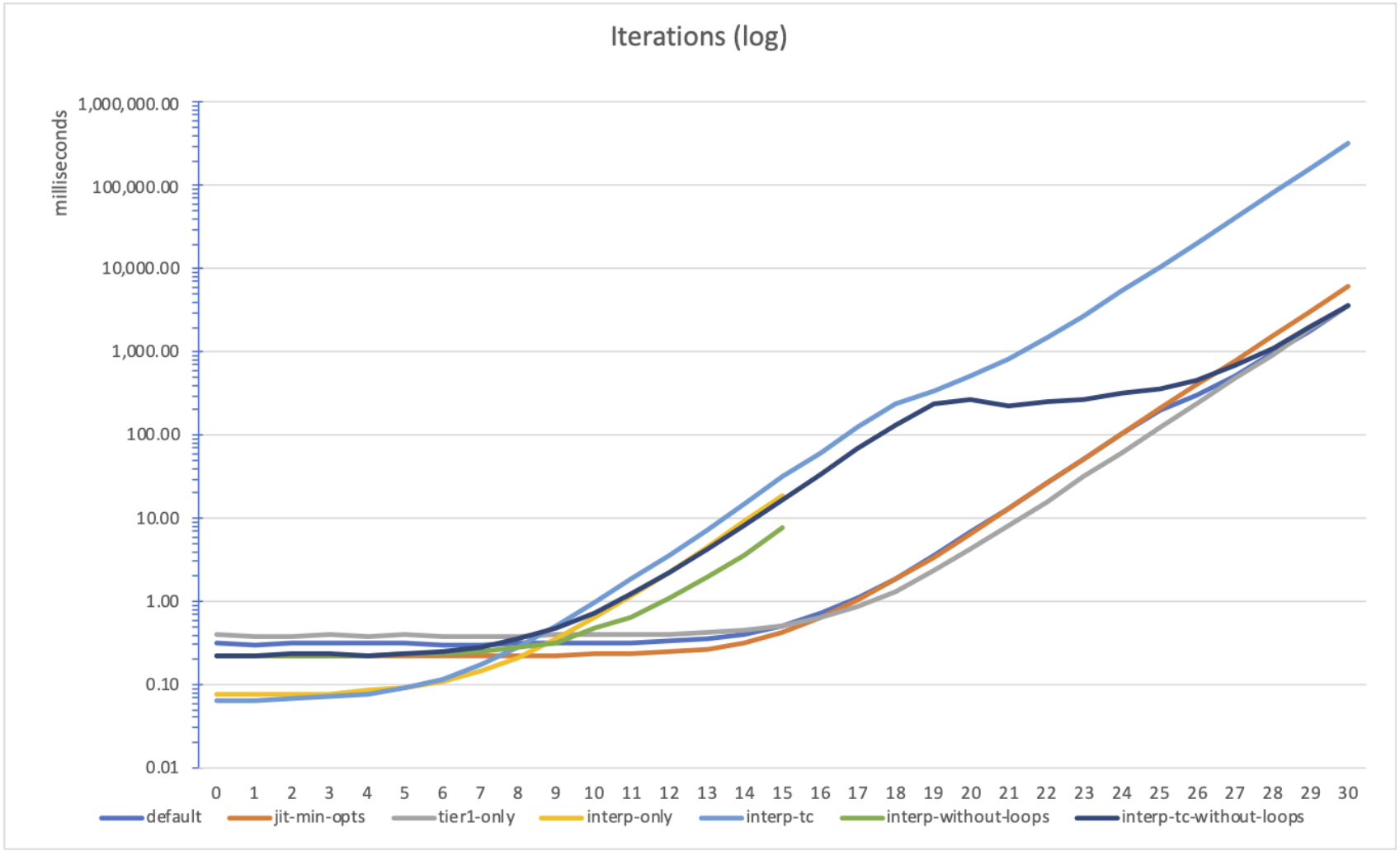

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- At a patchpoint, the **live state** of the ongoing computation must be identifiable (e.g. registers, stack slots, return address, implicit arguments).

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- **Option #2** might be easier to implement without updates to the original pieces of memory.

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- TIL from Beautiful Plots
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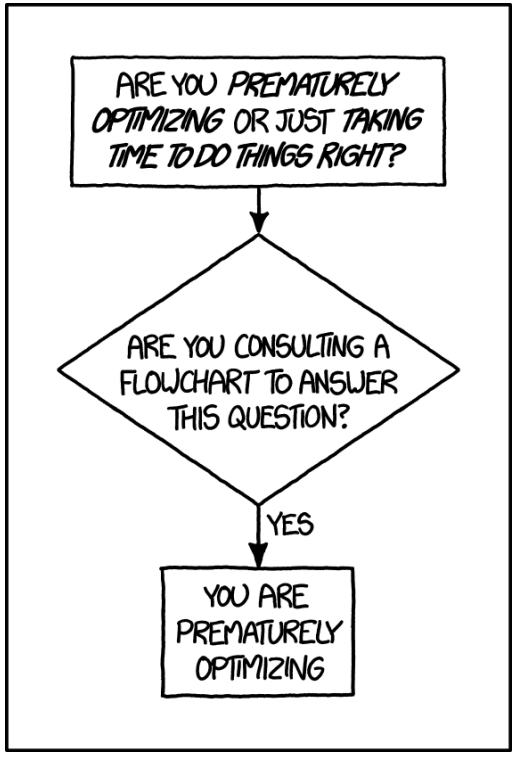

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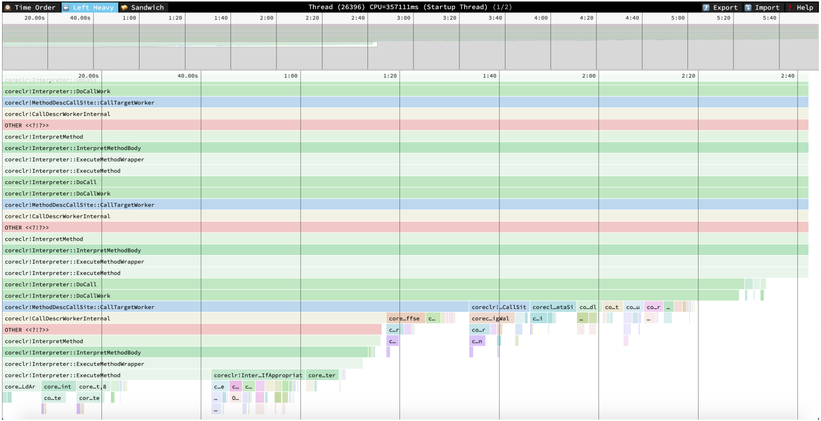

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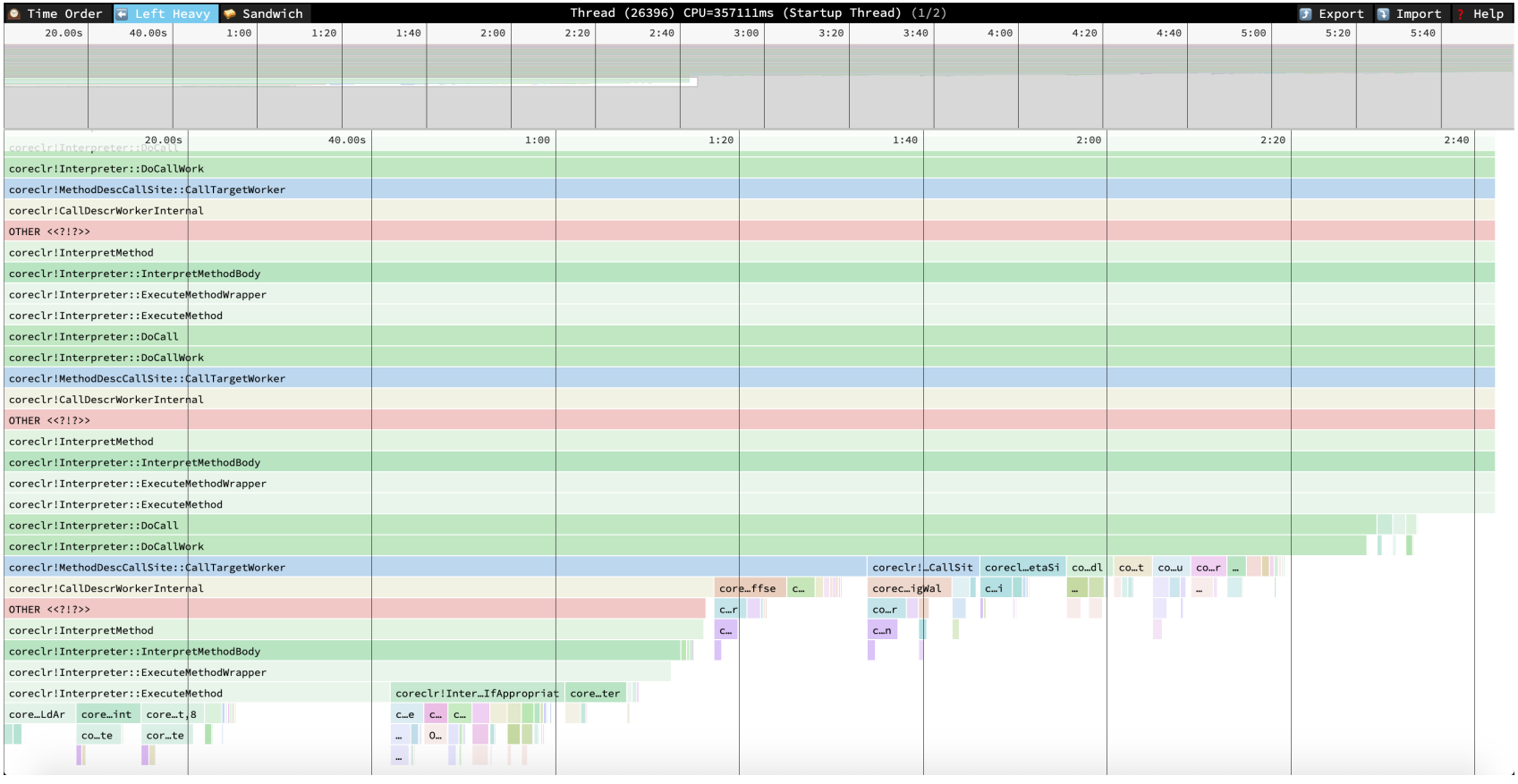

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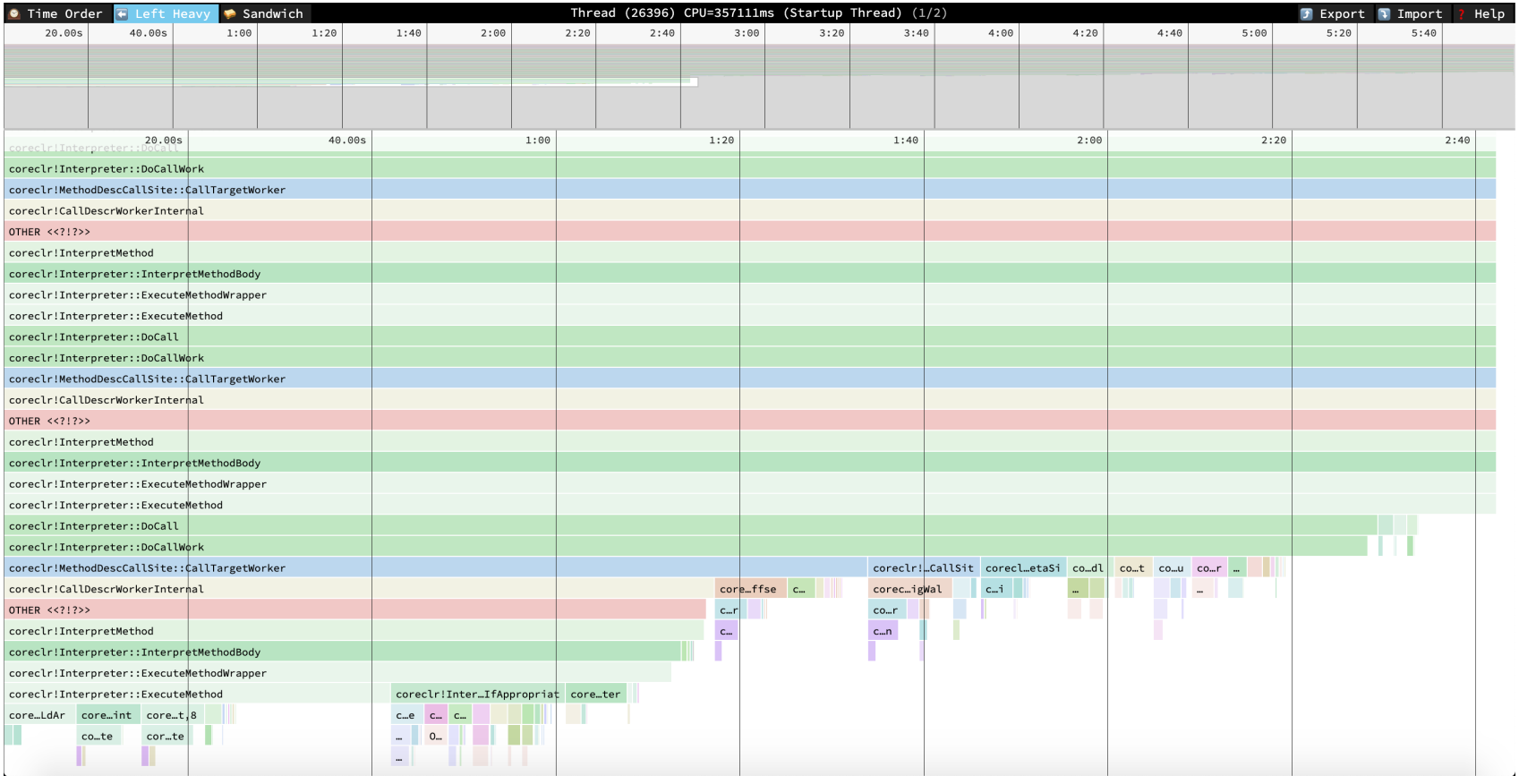

- The pattern of the call stack suggests that `DoCall` and `DoCallWork` take a large portion of inclusive time.
- **Question:** Which callees (direct or indirect) of `DoCallWork` have large inclusive and exclusive time?

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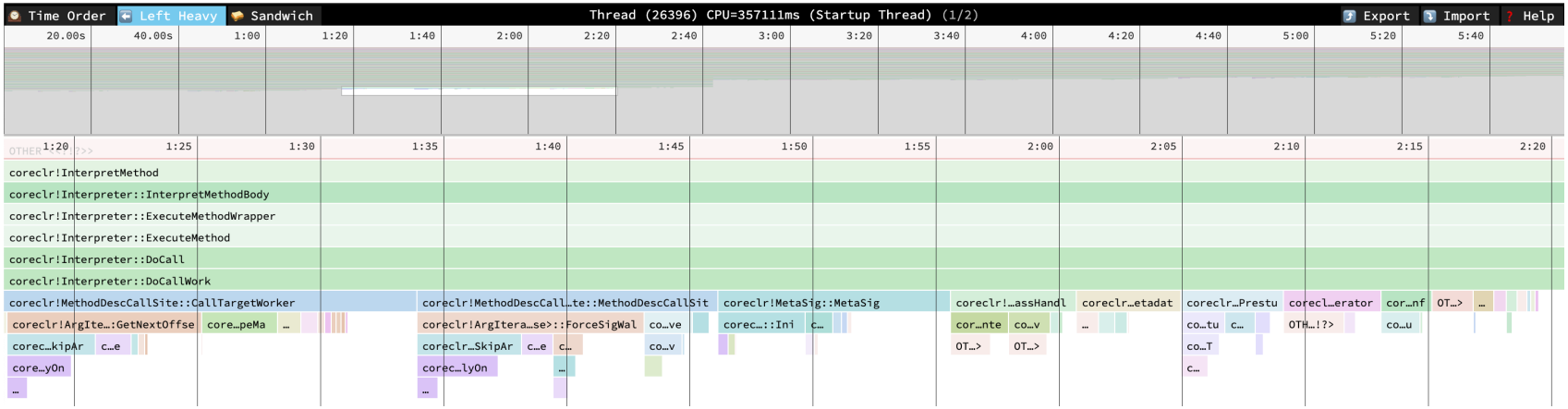

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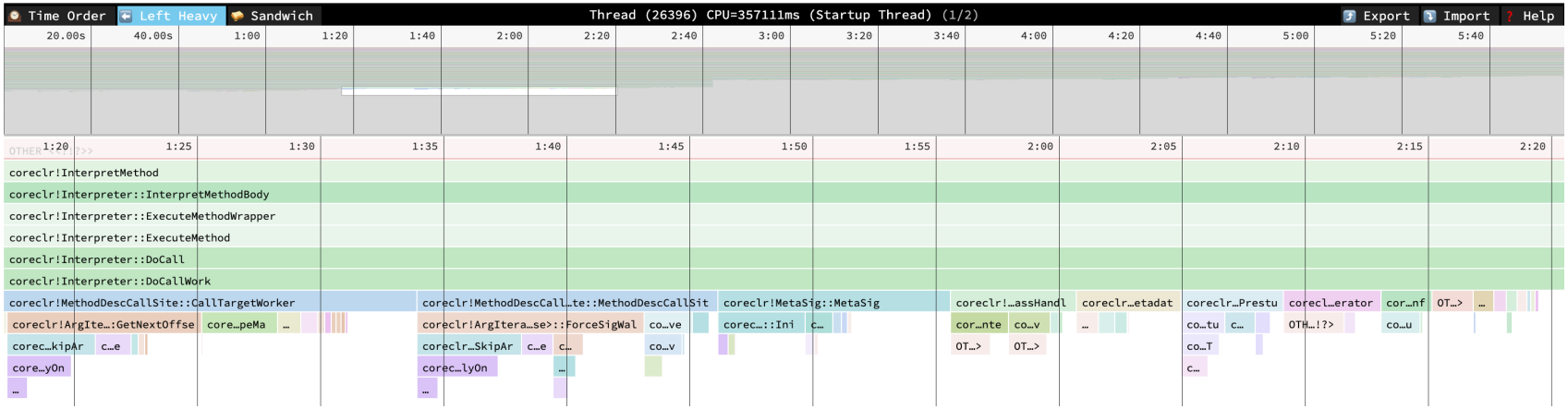

Name	Exc %	Exc
coreclr!Interpreter::ExecuteMethod	16.4	26,605
OTHER <<ntdll!?>>	7.2	11,658
coreclr!Interpreter::ThrowOnInvalidPointer	6.6	10,724
coreclr!Interpreter::DoCallWork	6.4	10,339
coreclr!Interpreter::LdArg	5.0	8,157
coreclr!MetaSig::MetaSig	4.0	6,492
coreclr!SigParser::SkipExactlyOne	4.0	6,420
coreclr!Interpreter::JitMethodIfAppropriate	3.4	5,569
coreclr!MethodDescCallSite::CallTargetWorker	3.4	5,546
coreclr!Interpreter::ExecuteMethodWrapper	3.0	4,790
coreclr!Interpreter::Interpreter	2.8	4,489
coreclr!ArgIteratorTemplate<ArgIteratorBase>::ForceSigWalk	2.3	3,713
coreclr!CEEInfo::getMethodNameFromMetadata	2.1	3,414
coreclr!Interpreter::BrOnComparison<3,0,1>	2.0	3,172
coreclr!MetaSig::Init	1.9	3,161
coreclr!FillInRegTypeMap	1.9	3,110
coreclr!ArgIteratorTemplate<ArgIteratorBase>::GetNextOffset	1.8	2,888
coreclr!SigPointer::PeekElemTypeNormalized	1.7	2,773
coreclr!ILCodeVersion::GetActiveNativeCodeVersion	1.6	2,620
coreclr!InterpretMethod	1.6	2,565
coreclr!InterpreterType::IsLargeStruct	1.5	2,477
coreclr!MethodDesc::IsPointingToPrestub	1.5	2,396
coreclr!Interpreter::StInd<int>	1.3	2,118
coreclr!MapSHash<CORINFO_METHOD_STRUCT_*,Interpreter::MethInfo,NoRemoveSHashTraits<MapSHashTraits<CORINFO_METHOD_STRUCT_*,Interpreter::MethInfo> > >::Lookup	1.3	2,104
coreclr!PEDecoder::CheckILMethod	1.3	2,080
coreclr!MethodDesc::EnsureActive	1.2	1,996
coreclr!MetaSig::SkipArg	1.2	1,936
coreclr!COR_ILMETHOD_DECODER::COR_ILMETHOD_DECODER	1.1	1,812
coreclr!Precode::IsPointingToPrestub	1.1	1,806
coreclr!CEEJitInfo::CEEJitInfo	1.1	1,719
OTHER <<ucrtbase!?>>	1.1	1,707

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- `ForceSigWalk` handles calling conventions for callees, and enumerates each argument of a signature in turn.
- **Question:** Can this information of mapping arguments to registers be cached somehow? If we repeatedly call a method, can we let the arguments stay in the registers?

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- **Question:** Can this information also be cached somehow?

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```
// CYCLE PROFILE: BEFORE ARG PROCESSING.

if (sigInfo.hasThis())
{
    if (m_callThisArg != NULL)
    {
        if (size_t(m_callThisArg) == 0x1)
        {
            args[curArgSlot] = NULL;
        }
        else
        {
            args[curArgSlot] = PtrToArgSlot(m_callThisArg);
        }
        argTypes[curArgSlot] = InterpreterType(CORINFO_TYPE_BYREF);
    }
    else
    {
        args[curArgSlot] = PtrToArgSlot(OpStackGet<void*>(argsBase + arg));
        argTypes[curArgSlot] = OpStackTypeGet(argsBase + arg);
        arg++;
    }
    // AV -> NullRef translation is NYI for the interpreter,
    // so we should manually check and throw the correct exception.
    if (args[curArgSlot] == NULL)
    {
        // If we're calling a constructor, we bypass this check since the runtime
        // should have thrown OOM if it was unable to allocate an instance.
        if (m_callThisArg == NULL)
        {
            _ASSERTE(!methToCall->IsStatic());
            ThrowNullPointerException();
        }
        // ...except in the case of strings, which are both
        // allocated and initialized by their special constructor.
        else
        {
            _ASSERTE(methToCall->IsCtor() && methToCall->GetMethodTable()->IsString());
        }
    }
    curArgSlot++;
}
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            const char* className = NULL;
            const char* methodName = m_interpCeeInfo.getMethodNameFromMetadata((CORINFO_METHOD_HANDLE)methToCall, &className, &namespaceName, NULL);
            if (
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                strcmp(namespaceName, "System.Runtime.Intrinsics.X86") == 0 &&
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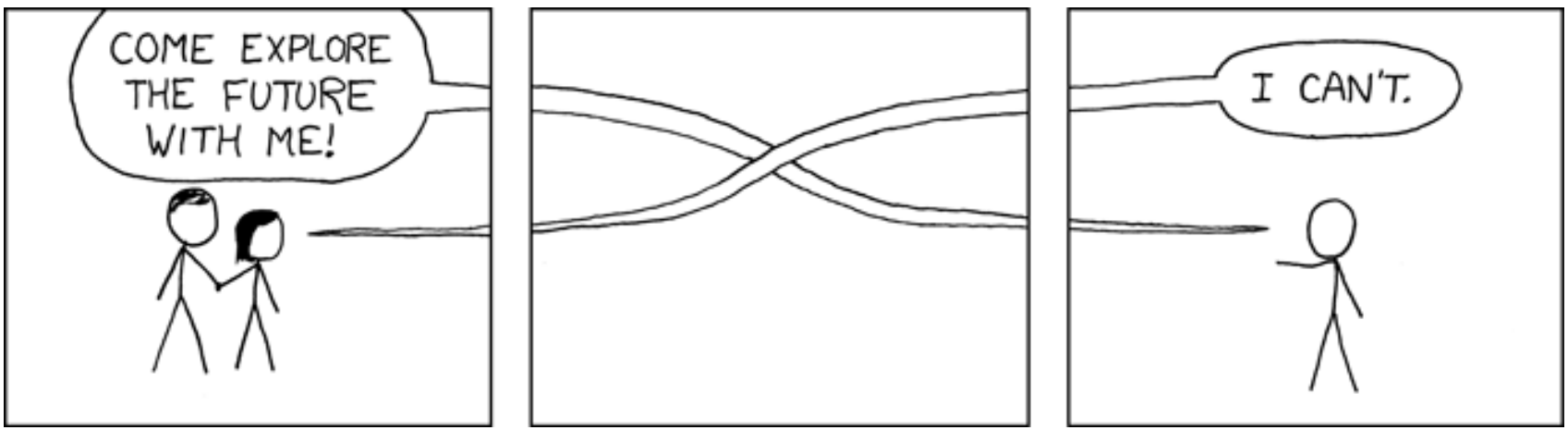

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Questions & Answers

Appendix

- **Issue #1:** The C++ compiler treats `reinterpret_cast` from a pointer to an integral type as an error.

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- **Fix:**

```
reinterpret_cast<short>(ArgSlotEndianessFixup(directOffset, sizeof(void*)));
static_cast<short>(reinterpret_cast<intptr_t>(ArgSlotEndianessFixup(directOffset, sizeof(void*))));
```

Appendix

- **Issue #2:** The C++ compiler treats the conversion from a generic type `T` to an integral type as an error.

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- **Issue #2:** The C++ compiler treats the conversion from a generic type `T` to an integral type as an error.
- **Fix:** There are finitely many integral types as `CORINFO_TYPE`. Hence we can condition on `sizeof(T)` to determine which integral type to which `T` is equivalent.

```
// Widen narrow types.
int ires;
switch (sizeof(T))
{
case 1:
    ires = std::is_same<T, INT8>::value ?
           static_cast<int>(reinterpret_cast<INT8*>(res_ptr)[index]) :
           static_cast<int>(reinterpret_cast<UINT8*>(res_ptr)[index]);
    break;
case 2:
    ires = std::is_same<T, INT16>::value ?
           static_cast<int>(reinterpret_cast<INT16*>(res_ptr)[index]) :
           static_cast<int>(reinterpret_cast<UINT16*>(res_ptr)[index]);
    break;
case 4:
    ires = std::is_same<T, INT32>::value ?
           static_cast<int>(reinterpret_cast<INT32*>(res_ptr)[index]) :
           static_cast<int>(reinterpret_cast<UINT32*>(res_ptr)[index]);
    break;
default:
    _ASSERTE_MSG(false, "This should have exhausted all the possible sizes.");
    break;
}
```

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- **Issue #4:** `LockHolder` is missing for synchronization.
- **Fix:**

```
#ifdef FEATURE_TIERED_COMPILATION
            CodeVersionManager::LockHolder _lockHolder;
            NativeCodeVersion activeCodeVersion = md->GetCodeVersionManager()->GetActiveILCodeVersion(md).GetActiveNativeCodeVersion(md);
            ILCodeVersion ilCodeVersion = activeCodeVersion.GetILCodeVersion();
            if (activeCodeVersion.GetOptimizationTier() == NativeCodeVersion::OptimizationTier0 &&
                !ilCodeVersion.HasAnyOptimizedNativeCodeVersion(activeCodeVersion))
            {
                tieredCompilationManager->AsyncPromoteToTier1(activeCodeVersion, &scheduleTieringBackgroundWork);
            }
#else
#error FEATURE_INTERPRETER depends on FEATURE_TIERED_COMPILATION now
#endif
```

Appendix

- **Issue #5:** "Bad IL Format" for virtual calls.
- **Fix:** Enable the `CORINFO_CALLINFO_CALLVIRT` flag in the call info for virtual calls.

```
combine(CORINFO_CALLINFO_SECURITYCHECKS,CORINFO_CALLINFO_LDFTN),
&callInfo);
  combine(CORINFO_CALLINFO_CALLVIRT,
          combine(CORINFO_CALLINFO_SECURITYCHECKS,
                  CORINFO_CALLINFO_LDFTN)),
  &callInfo);
```

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```
.method public hidebysig specialname static
        bool  get_IsSupported() cil managed
{
  // Code size       6 (0x6)
  .maxstack  8
  IL_0000:  call       bool System.Runtime.Intrinsics.X86.Sse2::get_IsSupported()
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} // end of method Sse2::get_IsSupported
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- **“Fix” (a.k.a. Workaround):** Force the interpreter to return `false` for `get_IsSupported()` to disable hardware intrinsics.

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- Controlled by the COM+ environment variable `InterpreterHWIntrinsicsIsSupportedFalse`

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class GenericRenderingEngine : RenderingEngine
{
    virtual void Render()
    {
        Debug.Assert(!Avx.IsSupported);
        // ...
    }

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