LLVM & HPSSA

Hot Path SSA Form in LLVM

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What we modified in LLVM Source?

- New `llvm::intrinsic` signature, `"llvm.tau"` to support addition and removal of τ-functions to the LLVM SSA IR representation.

```
+ //===---------- intrinsic for tau ------------------=====//
+ def int_tau : DefaultAttrsIntrinsic<[llvm_any_ty],
+                    [llvm_vararg_ty],
+                    []>;
```

What we modified in LLVM Source?

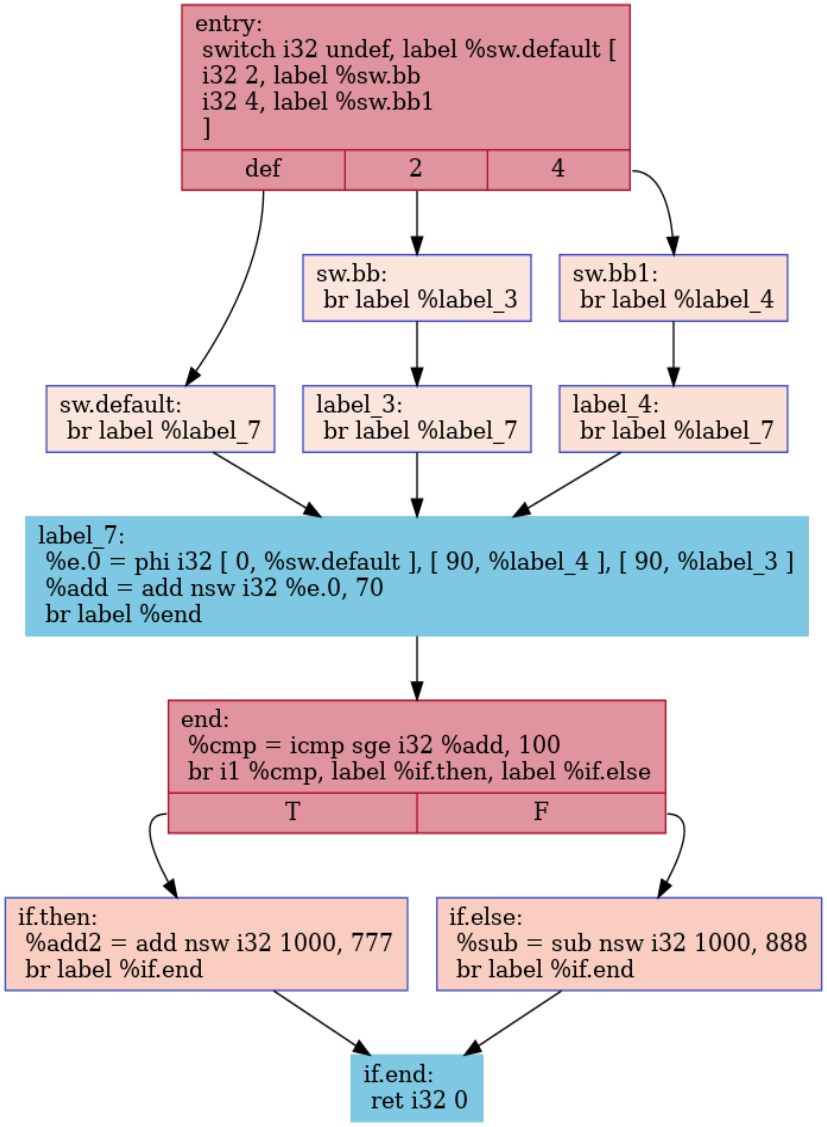
- Modified `Verifier::verifyDominatesUse()` function since we don't want our intrinsic to interfere with `dominators` computation.

```
1  + //========== Changes for tau.intrinsic ================//
2  void Verifier::verifyDominatesUse(Instruction &I, unsigned i) {
3    Instruction *Op = cast<Instruction>(I.getOperand(i));
4    +  if (CallInst *CI = dyn_cast<CallInst>(&I)) {
5    +  Function *CallFunction = CI->getCalledFunction();
6    +  if (CallFunction != NULL && CallFunction->getIntrinsicID()==
7    +    Function::lookupIntrinsicID("llvm.tau")) {
8    +      return;
9    +    }
10   +  }
```

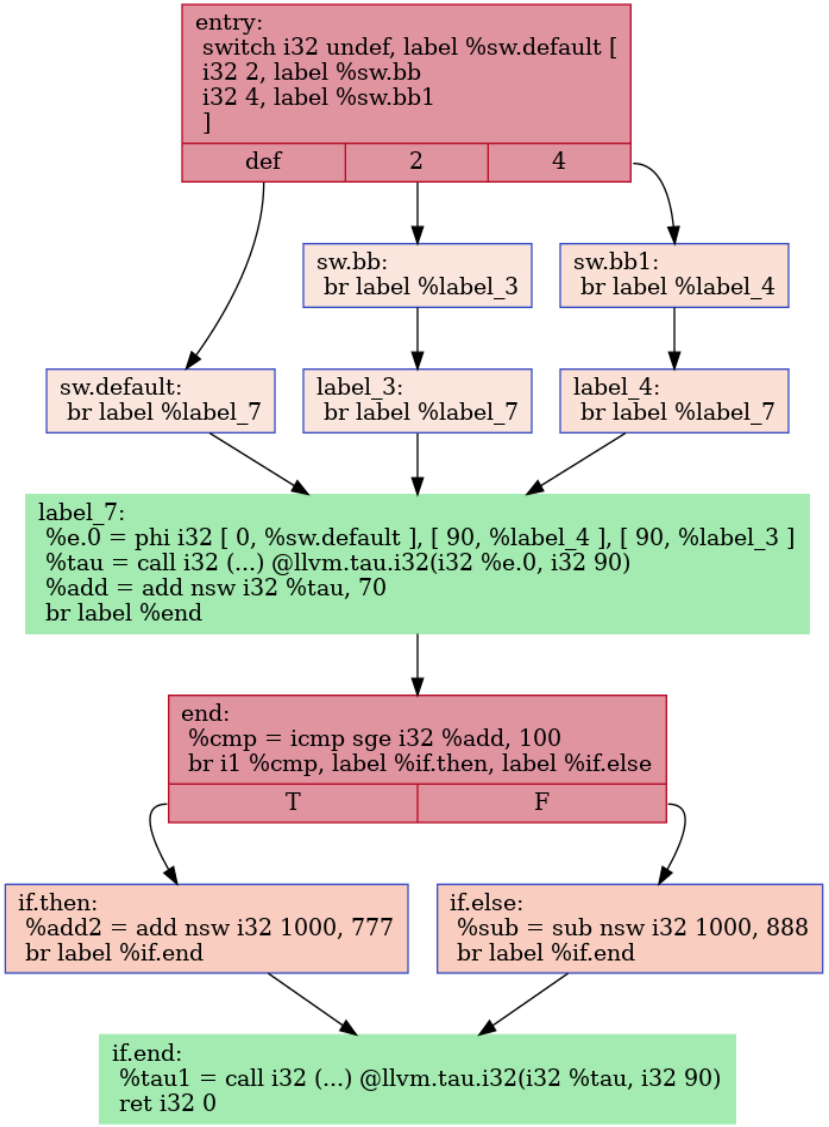
HPSSAPass : Overview

- `class HPSSAPass : public PassInfoMixin<HPSSAPass>`
  - Implemented `llvm::HPSSAPass` pass using the new LLVM Pass Manager.
  - Function `HPSSAPass::run(Function \&F, ...)` runs over a `llvm::Function` and inserts `"llvm.tau"` intrinsic calls with speculative and safe arguments at strategic positions in the LLVM IR and handles argument allocation for `"llvm.tau"` intrinsic calls as described in the previous slides.
- Key HPSSA Data Structures :
  - Hot Path Set using `llvm::BitVector` for maintaining hot paths in the program.
  - Definition Accumalator, `defAccumulator(op, currBB)` function. The argument "op" is a phi argument that reaches basic-block "currBB" via hot path .
  - A stack of map values `std::map<Value*,Value*>` to store the most "recent" tau definition encountered so far corresponding for a tau variable used later in variable renaming.

HPSSA Transformation



CFG for 'main' function before HPSSA Pass



CFG for 'main' function after HPSSA Pass

HPSSAPass : Main Pass

- `HPSSAPass::run(Function \&F, FunctionAnalysisManager \&AM)`
  - Invoke `HPSSAPass::getProfileInfo()` function to get a compact representation of all the profiled hot paths in the program and then call `HPSSAPass::getCaloricConnector()` to get all the caloric connectors from the hot path information. This is a precursor to finding strategic positions to place `"llvm.tau"` intrinsic calls in the LLVM IR.
  - Runs over each basic block in the function "F" in topological order using iterator returned from `llvm::Function::RPOT()` call.
  - Uses the `llvm::dominates()` function from `llvm::DominatorTreeAnalysis` to check for dominance frontier while processing the child nodes of the current basic block. This step is a part of correctly placing `"llvm.tau"` intrinsic calls in the LLVM IR.
  - Uses the renaming stack and `HPSSAPass::Search()` function to search and replace all use of PHI result operand with that returned by the `"llvm.tau"` intrinsic call.

HPSSAPass : Destruction Pass

- Out of HPSSA Form.
  - A seperate pass using the new LLVM Pass Manager.
    `class TDSTRPass : public PassInfoMixin<TDSTRPass>`
  - Using `TDSTRPass::run(Function \&F, ...)`, we replace all use of existing tau operands with first argument of `"llvm.tau"` intrinsic (corresponds to the safe argument) and remove the `"llvm.tau"` intrinsic calll from the LLVM IR.
  - The LLVM IR becomes identical to what it was before running the HPSSA Pass.

HPSSAPass : Usage [It is easy!]

- Include `llvm::HPSSAPass` header file.
- Load shared object using opt tool. `opt -load HPSSA.cpp.so ...`

```
1  #include <HPSSA.h> // import the header.
2
3  class MyExamplePass : public PassInfoMixin<MyExamplePass> {
4    public: PreservedAnalyses run(Function &F,
5      FunctionAnalysisManager &AM);
6  };
7  ...
8
9  PreservedAnalyses MyExamplePass::run(Function &F,
10   FunctionAnalysisManager &AM) {
11   if (F.getName() != "main")
12     return PreservedAnalyses::all();
13
14   HPSSAPass hpssaUtil; // Make a HPSSAPass Object.
15   hpssaUtil.run(F, AM);  // Call the HPSSAPass::run() function.
16
17   std::vector<Instruction *> TauInsts
18     = hpssaUtil.getAllTauInstrunctions(F); // Calling HPSSA utility function.
19
20   std::cout << "\t\tTotal Tau Instructions : " << TauInsts.size() << "\n";
21   ...
22 }
23
24 /// [output] Total Tau Instructions : 7
```

New Additions to SCCP Pass

- We implement a speculative version of the SCCP to demonstrate the usefulness of the HPSSA Form.
- Modified the existing SCCP Pass to add in `SCCPInstVisitor::visitTauNode()` function similar to `SCCPInstVisitor::visitPHINode()`, which handles the special `"llvm.tau"` intrinsic instructions added for τ-functions.
- Added a new lattice element type `"spec_constant"` in `ValueLattice` class supporting operations on speculative constants.
- Added new functions in the `SCCPInstVisitor` and `SCCPSolver` class to handle operations on speculative constants. Eg. Operands can be marked speculative using `markSpeculativeConstant()` function.

Further Modifications

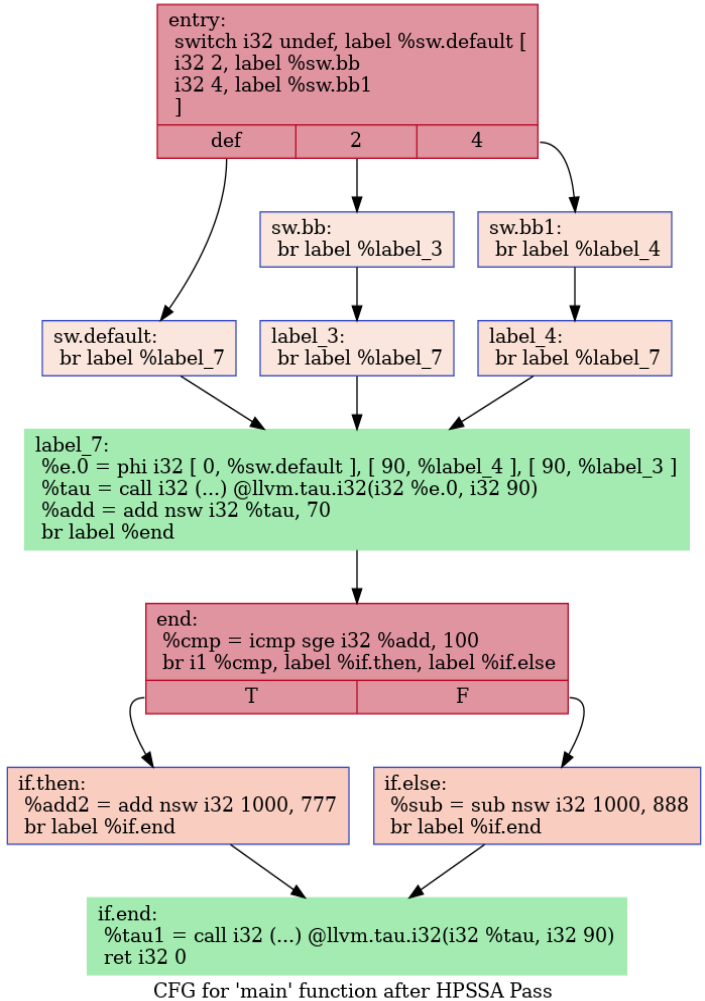
- Modified the `SCCPInstVisitor::mergeIn()` function to handle lattice "meet" operation for the new speculative constants introduced.
- Since we added the τ-functions as an `"llvm.tau"` intrinsic which is essentially an `llvm:CallInst` type, we modified all appropriate visit and marking functions in `SCCPInstVisitor`, `SCCPSolver` and `SCCPPass` to handle this case separately by calling `visitTauNode()`.
- Modified utility functions in `SCCPInstVisitor` and `SCCPSolver` class to print marking of speculative constants and related operations for debugging purpose.

```
1  ... // logs
2  [BBWorkList] Visiting LLVM Instrinsic : llvm.tau (call)
3    Visiting Tau Instruction
4      Speculative Operand : , speculative constant
5      Speculative Operand : llvm.tau.i32, speculative constant
6    Merged speculative constant into   %tau = call i32 (...)
7      @llvm.tau.i32(i32 %e.0, i32 90) : speculative constant
8    ValueLattice (TauState) : speculative constant
9  ...
```

SSCCP with an Example

We run the speculative SCCP on the example below.

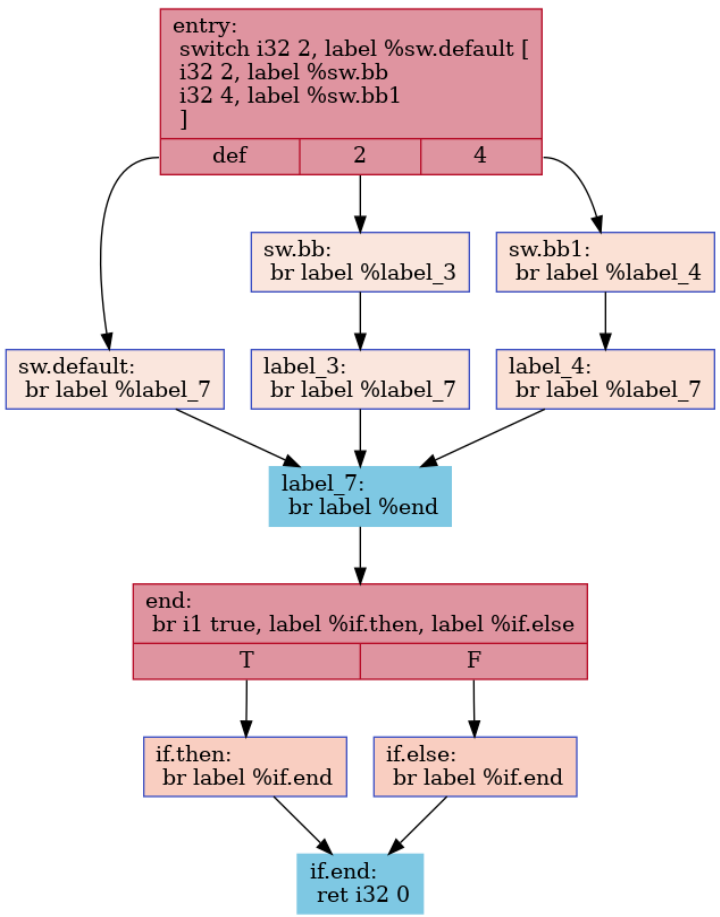
```
1   int main() {
2     int a = 1000, z, c, e = 0;
3     switch(c) {
4       case 2 : goto label_3; break;
5       case 4 : goto label_4; break;
6       default : goto label_7;
7     }
8     label_3:
9       e = 90;
10      goto label_7;
11    label_4:
12      e = 100 - 10;
13      goto label_7;
14    label_7:
15    // e in rhs is 90.
16      e = e + 70;
17      goto end;
18    end:
19    // e is greater than 100 always
20      if (e >= 100) {
21        a = a + 777;
22      } else {
23        a = a - 888;
24      } return 0;
25  }
```



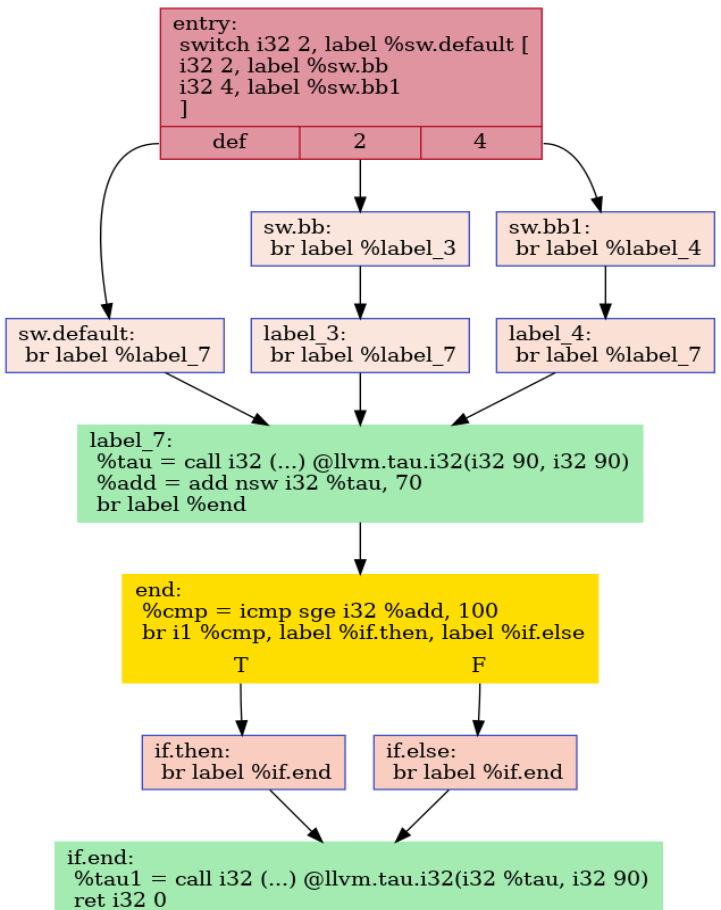
CFG for 'main' function after HPSSA Pass

SSCCP with an Example

- The PHINODE at `label_7` is removed due to constant propagation of value 90 for variable "e" along all paths. However since the operands of the τ-function are marked speculative, this instruction and it's uses are not removed by the SSCCP Pass.



SCCP running on 'main' function.



Speculative SCCP running on 'main' function