LLVM & HPSSA

Hot Path SSA Form in LLVM

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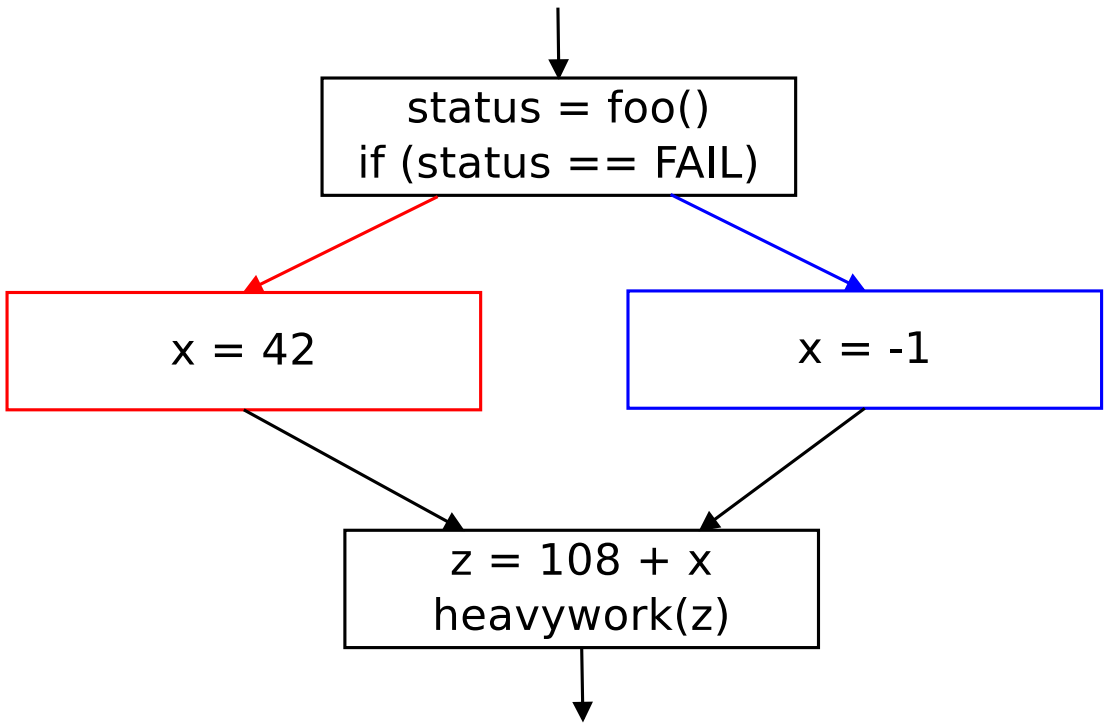
Section 1

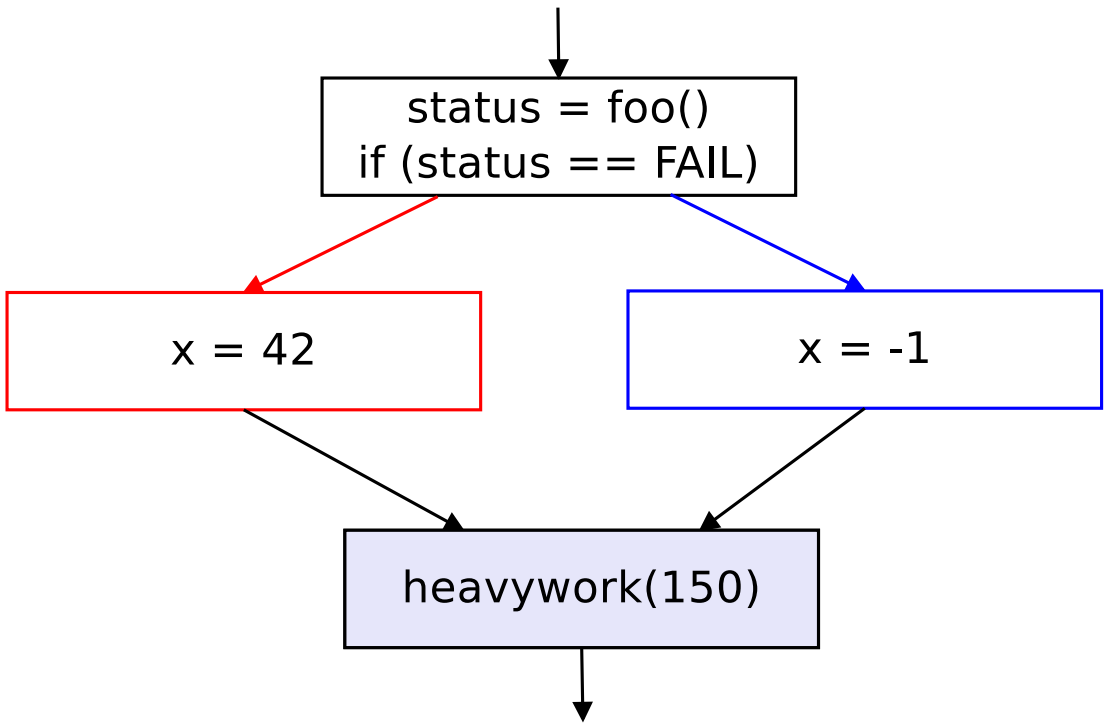
Doing Speculative Analysis is Hard !

Importance of speculative analysis. It is hard to do. Whole research papers dedicated to single speculative analysis. But with HPSSA form it's a breeze.

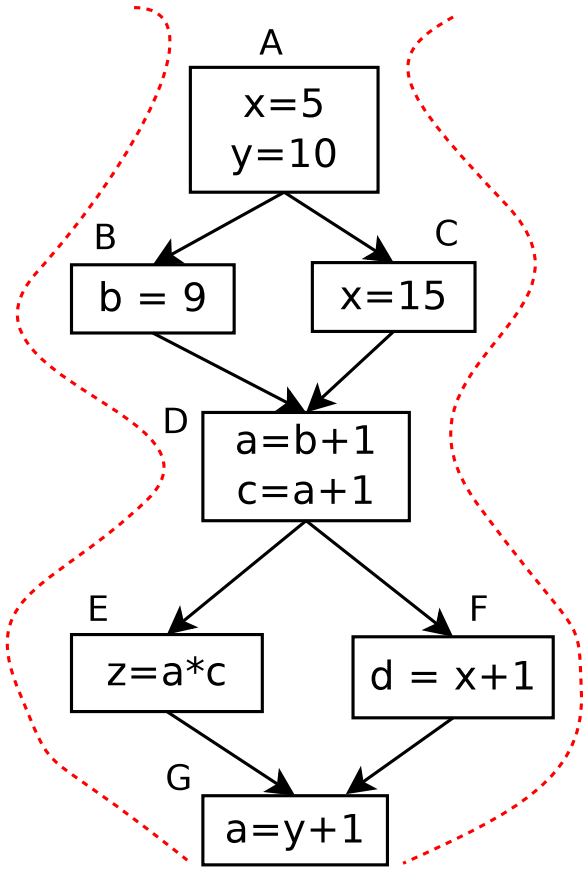
A case for profile-guided optimizations (PGO)



A case for profile-guided optimizations (PGO)



Profile-guided analysis on paths



Summary

- Profile-guided analysis across paths is stronger—can capture correlations between control-flow of basic-blocks
- Collecting path-profiles seems challenging—requires "recording" of a sequence of basic-blocks

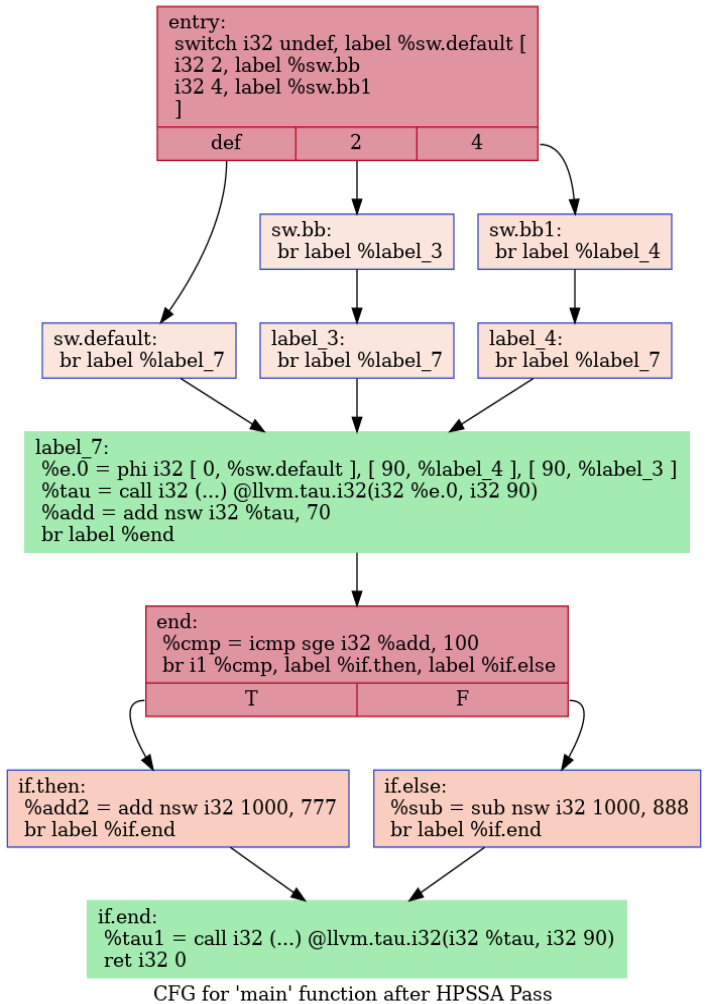
Case Study : Speculative SCCP Pass

- We implement a speculative version of the SCCP to demonstrate the usefulness of the HPSSA Form.
- Modified the existing SCCP Pass to add in a function which handles the special `"llvm.tau"` intrinsic instructions used for τ-functions. (8 lines extra of code only!)
- Added a new lattice element type `"spec_constant"` in `ValueLattice` class supporting operations on speculative constants. (5 lines extra of code only!)
- Added new functions in the `SCCPInstVisitor` and `SCCPSolver` class to handle operations on speculative constants. Eg. Operands can be marked speculative using `markSpeculativeConstant()` function. (5 lines extra of code only!)

SSCCP with an Example

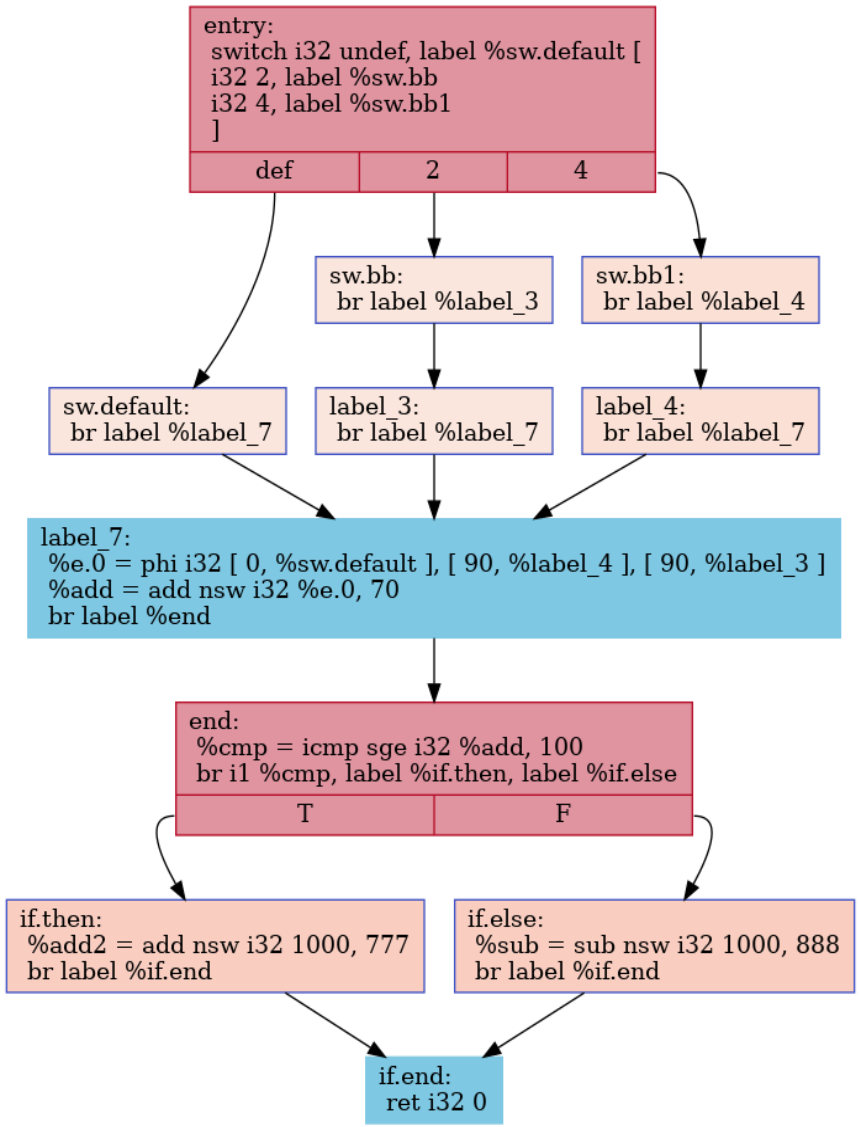
We run the speculative SCCP on the example below. Mark the different types of variables. Make the CFG look pretty and add hot path. .

```
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      }
25    return 0;
26  }
```



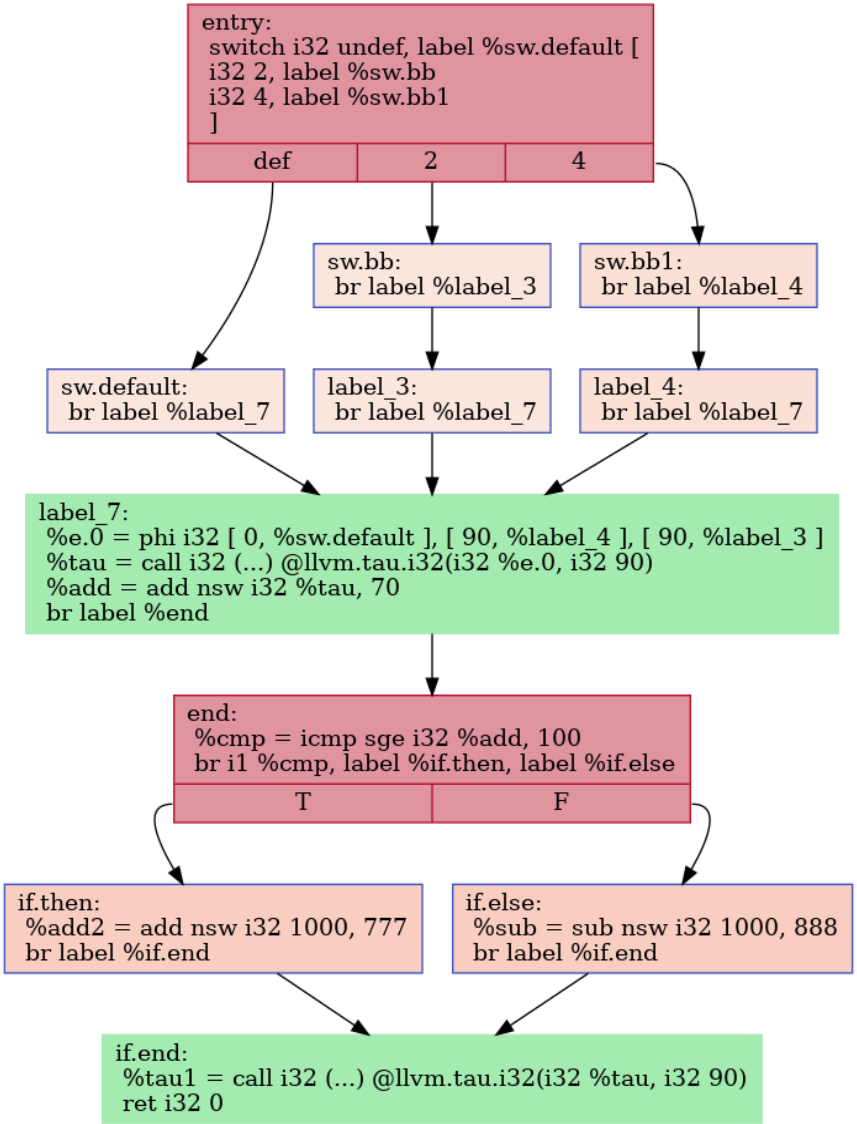
CFG for 'main' function after HPSSA Pass

TODO : SCCP pass running on Example.



CFG for 'main' function before HPSSA Pass

TODO : Speculative SCCP pass running on Example.



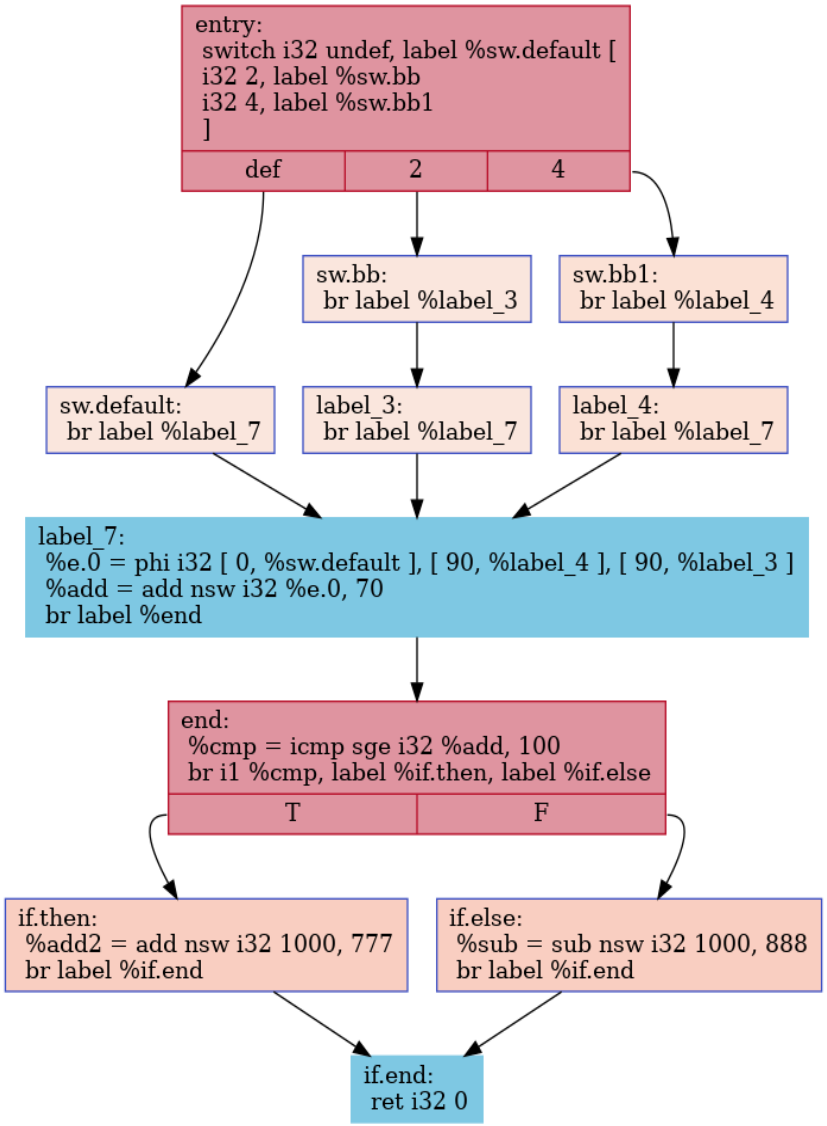
CFG for 'main' function after HPSSA Pass

Section 2

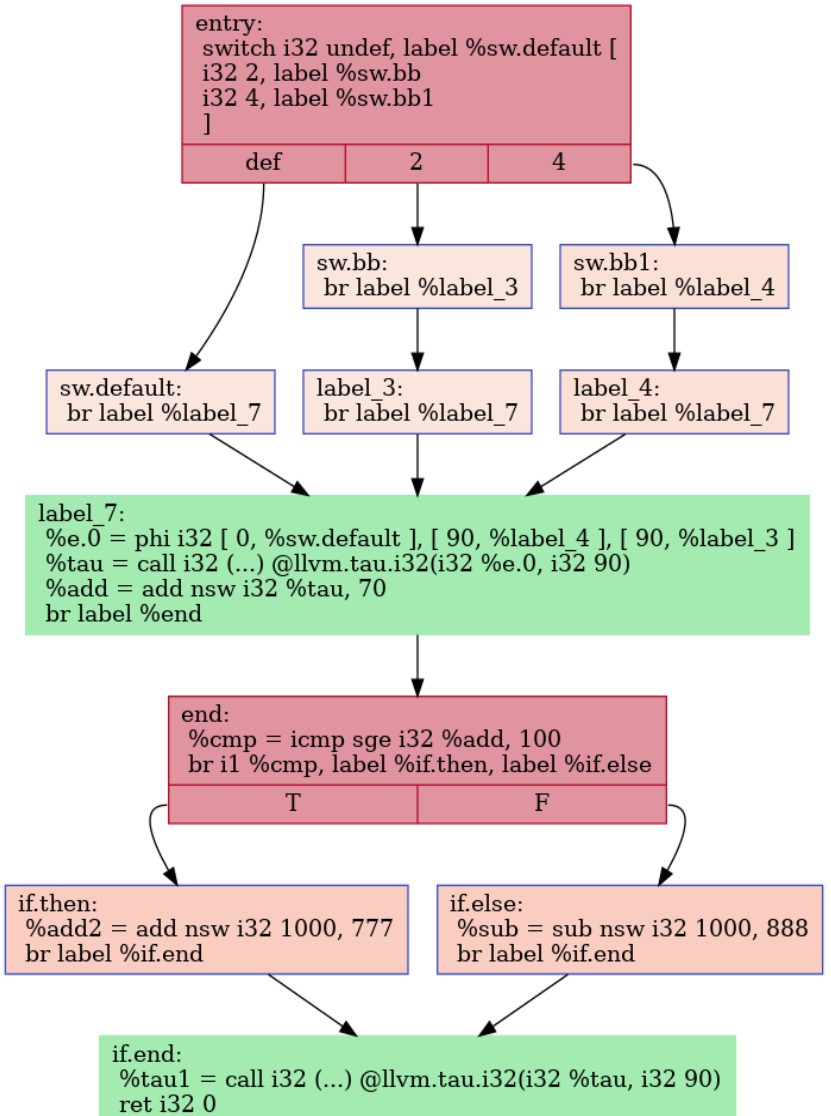
HPSSAPass : Overview

- `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.

Section 3

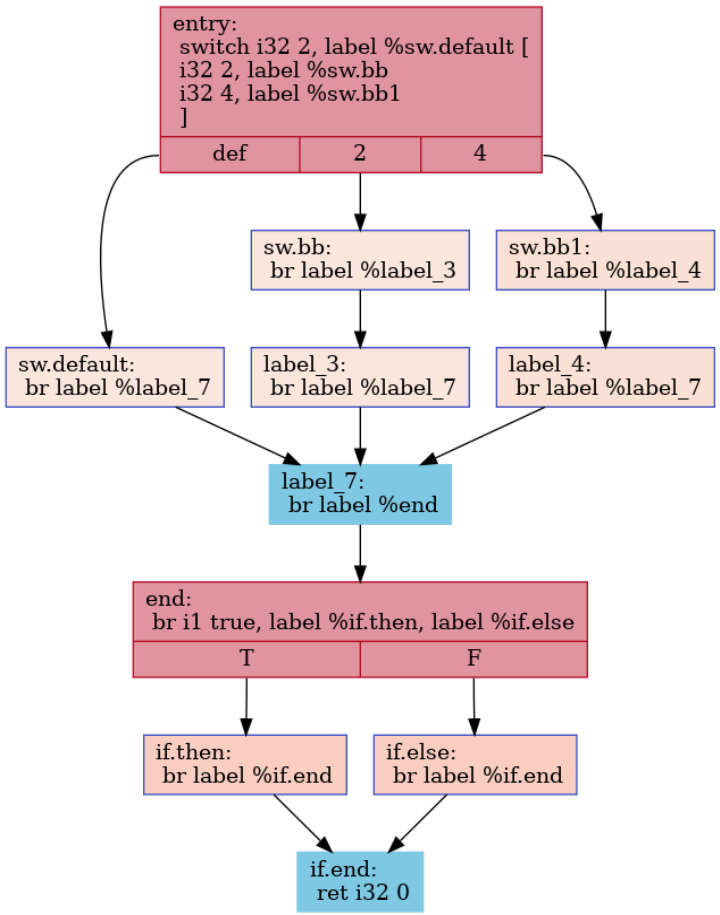
Further Modifications

- 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.

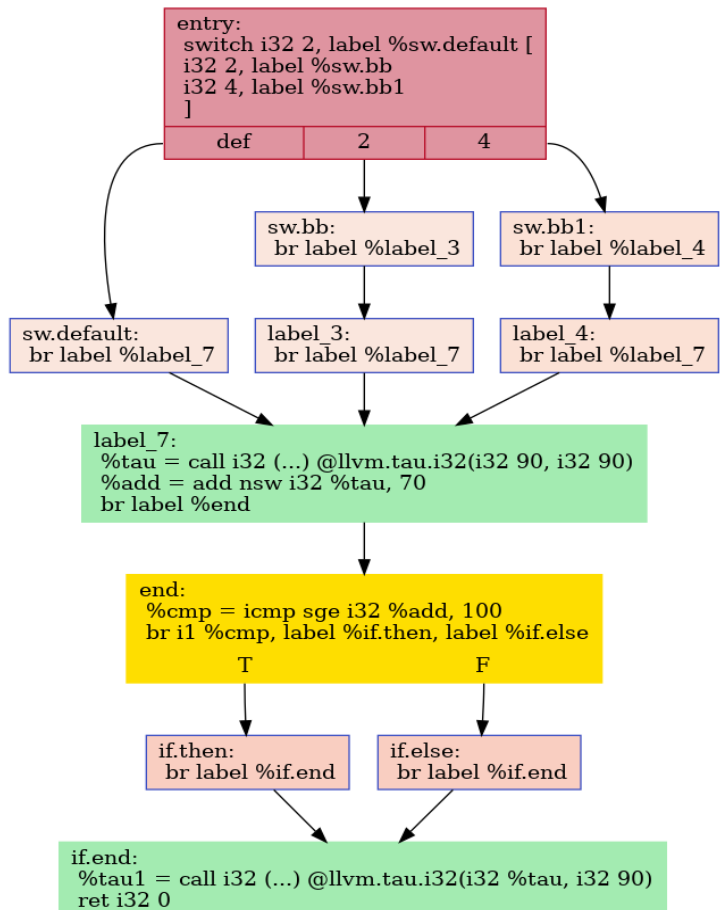
```
1  ... // logs
2  [BBWorkList] Visiting LLVM Instrinsic : llvm.tau (call)
3    Visiting Tau Instruction
4      Speculative Operand : , speculative constant
5      Speculative Operand : llvm.tau.i32, speculative constant
6    Merged speculative constant into   %tau = call i32 (...)
7      @llvm.tau.i32(i32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

SSCCP with an Example

- 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

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
```

Section 4

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],
+                   []>;
```

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

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