CS738: Advanced Compiler Optimizations

Sparse Conditional Constant Propagation

Amey Karkare
karkare@cse.iitk.ac.in

http://www.cse.iitk.ac.in/~karkare/cs738
Department of CSE, IIT Kanpur

Sparse Simple Constant Propagation (SSC)

- Improved analysis time over Simple Constant Propagation

Sparse Simple Constant Propagation (SSC)

- Improved analysis time over Simple Constant Propagation
- Finds all simple constant

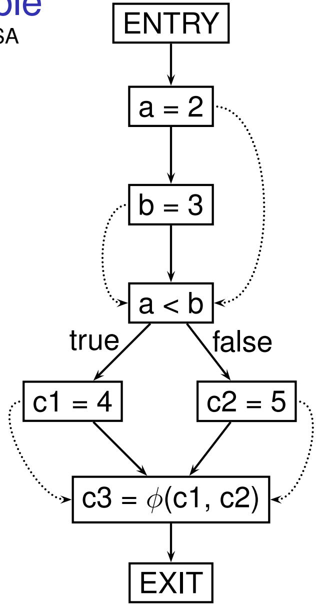
Sparse Simple Constant Propagation (SSC)

- Improved analysis time over Simple Constant Propagation
- Finds all simple constant
  - Same class as Simple Constant Propagation

Motivating Example

Dashed edges denote SSA

def-use chains



Preparations for SSC Analysis

- Convert the program to SSA form

Preparations for SSC Analysis

- Convert the program to SSA form
- One statement per basic block

Preparations for SSC Analysis

- Convert the program to SSA form
- One statement per basic block
- Add connections called *SSA edges*

Preparations for SSC Analysis

- Convert the program to SSA form
- One statement per basic block
- Add connections called *SSA edges*
  - Connect (unique) definition point of a variable to its use points

Preparations for SSC Analysis

- Convert the program to SSA form
- One statement per basic block
- Add connections called *SSA edges*
  - Connect (unique) definition point of a variable to its use points
  - Same as *def-use* chains

SSC Algorithm: Initialization

- Evaluate expressions involving constants only and assign the value (c) to variable on LHS

SSC Algorithm: Initialization

- Evaluate expressions involving constants only and assign the value (c) to variable on LHS
- If expression can not be evaluated at compile time, assign $\perp$

SSC Algorithm: Initialization

- Evaluate expressions involving constants only and assign the value (c) to variable on LHS
- If expression can not be evaluated at compile time, assign $\bot$
- Else (for expression contains variables) assign $\top$

SSC Algorithm: Initialization

- Evaluate expressions involving constants only and assign the value (c) to variable on LHS
- If expression can not be evaluated at compile time, assign $\perp$
- Else (for expression contains variables) assign $\top$
- Initialize worklist *WL* with SSA edges whose def is not $\top$

SSC Algorithm: Initialization

- Evaluate expressions involving constants only and assign the value (c) to variable on LHS
- If expression can not be evaluated at compile time, assign $\bot$
- Else (for expression contains variables) assign $\top$
- Initialize worklist *WL* with SSA edges whose def is not $\top$
- Algorithm terminates when *WL* is empty

SSC Algorithm: Iterative Actions

- Take an SSA edge E out of WL

SSC Algorithm: Iterative Actions

- Take an SSA edge *E* out of *WL*
- Take meet of the value at def end and the use end of *E* for the variable defined at def end

SSC Algorithm: Iterative Actions

- Take an SSA edge E out of WL
- Take meet of the value at def end and the use end of E for the variable defined at def end
- If the meet value is different from use value, replace the use by the meet

SSC Algorithm: Iterative Actions

- Take an SSA edge E out of WL
- Take meet of the value at def end and the use end of E for the variable defined at def end
- If the meet value is different from use value, replace the use by the meet
- Recompute the def d at the use end of E

SSC Algorithm: Iterative Actions

- Take an SSA edge E out of WL
- Take meet of the value at def end and the use end of E for the variable defined at def end
- If the meet value is different from use value, replace the use by the meet
- Recompute the def d at the use end of E
- If the recomputed value is *lower* than the stored value, add all SSA edges originating at d

Meet for ϕ-function

$$v = \phi(v_1, v_2, \ldots, v_k)$$

$$\Rightarrow \text{ValueOf}(v) = v_1 \wedge v_2 \wedge \ldots \wedge v_n$$

SSC Algorithm: Complexity

- Height of CP lattice = 2

SSC Algorithm: Complexity

- Height of CP lattice = 2
- Each SSA edge is examined at most twice, for each lowering

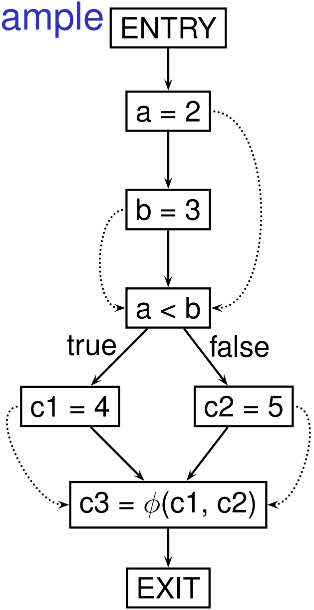
SSC Algorithm: Complexity

- Height of CP lattice = 2
- Each SSA edge is examined at most twice, for each lowering
- Theoretical size of SSA graph: $O(V \times E)$

SSC Algorithm: Complexity

- Height of CP lattice = 2
- Each SSA edge is examined at most twice, for each lowering
- Theoretical size of SSA graph: $O(V \times E)$
- Practical size: linear in the program size

SSC: Practice Example



SSC: Practice Example

What if we change “c1 = 4” to “c1 = 5”?

Sparse Conditional Constant Propagation (SCC)

- Constant Propagation with *unreachable code elimination*

Sparse Conditional Constant Propagation (SCC)

- Constant Propagation with *unreachable code elimination*
- Ignore definitions that reach a use via a non-executable edge

SCC Algorithm: Key Idea

$$v = \phi(v_1, v_2, \ldots, v_k)$$

$$\Rightarrow \text{ValueOf}(v) = \bigwedge_{i \in ExecutablePath} v_i$$

We ignore paths that are not "yet" marked executable

SCC Algorithm: Preparations

- Two Worklists

SCC Algorithm: Preparations

- Two Worklists
  - Flow Worklist (*FWL*)

SCC Algorithm: Preparations

- Two Worklists
  - Flow Worklist (*FWL*)
    - Worklist of flow graph edges

SCC Algorithm: Preparations

- Two Worklists
  - Flow Worklist (*FWL*)
    - Worklist of flow graph edges
  - SSA Worklist (*SWL*)

SCC Algorithm: Preparations

- Two Worklists
  - Flow Worklist (*FWL*)
    - Worklist of flow graph edges
  - SSA Worklist (*SWL*)
    - Worklist of SSA graph edges

SCC Algorithm: Preparations

- Two Worklists
  - Flow Worklist (*FWL*)
    - Worklist of flow graph edges
  - SSA Worklist (*SWL*)
    - Worklist of SSA graph edges
- Execution Halts when **both** worklists are empty

SCC Algorithm: Preparations

- Two Worklists
  - Flow Worklist (*FWL*)
    - Worklist of flow graph edges
  - SSA Worklist (*SWL*)
    - Worklist of SSA graph edges
- Execution Halts when **both** worklists are empty
- Associate a flag, the *ExecutableFlag*, with every flow graph edge to control the evaluation of ϕ-function in the destination node

SCC Algorithm: Initialization

- Initialize *FWL* to contain edges leaving ENTRY node

SCC Algorithm: Initialization

- Initialize *FWL* to contain edges leaving ENTRY node
- Initialize *SWL* to empty

SCC Algorithm: Initialization

- Initialize *FWL* to contain edges leaving ENTRY node
- Initialize *SWL* to empty
- Each *ExecutableFlag* is false initially

SCC Algorithm: Initialization

- Initialize *FWL* to contain edges leaving ENTRY node
- Initialize *SWL* to empty
- Each *ExecutableFlag* is false initially
- Each value is $\top$ initially (Optimistic)

SCC Algorithm: Iterations

- Remove an item from either worklist

SCC Algorithm: Iterations

- Remove an item from either worklist
- process the item (described next)

SCC Algorithm: Processing *FWL* Item

- Item is flow graph edge

SCC Algorithm: Processing *FWL* Item

- Item is flow graph edge
- If *ExecutableFlag* is true, do nothing

SCC Algorithm: Processing *FWL* Item

- Item is flow graph edge
- If *ExecutableFlag* is true, do nothing
- Otherwise

SCC Algorithm: Processing *FWL* Item

- Item is flow graph edge
- If *ExecutableFlag* is true, do nothing
- Otherwise
  - Mark the *ExecutableFlag* as true

SCC Algorithm: Processing *FWL* Item

- Item is flow graph edge
- If *ExecutableFlag* is true, do nothing
- Otherwise
  - Mark the *ExecutableFlag* as true
  - **Visit-**ϕ for all ϕ-functions in the destination

SCC Algorithm: Processing *FWL* Item

- Item is flow graph edge
- If *ExecutableFlag* is true, do nothing
- Otherwise
  - Mark the *ExecutableFlag* as true
  - **Visit-**ϕ for all ϕ-functions in the destination
  - If only one of the *ExecutableFlag*s of incoming flow graph edges for dest is true (dest visited for the first time), then **VisitExpression** for all expressions in dest

SCC Algorithm: Processing *FWL* Item

- Item is flow graph edge
- If *ExecutableFlag* is true, do nothing
- Otherwise
  - Mark the *ExecutableFlag* as true
  - **Visit-ϕ** for all ϕ-functions in the destination
  - If only one of the *ExecutableFlag*s of incoming flow graph edges for dest is true (dest visited for the first time), then **VisitExpression** for all expressions in dest
  - If the dest contains only one outgoing flow graph edge, add that edge to *FWL*

SCC Algorithm: Processing *SWL* Item

- Item is SSA edge

SCC Algorithm: Processing *SWL* Item

- Item is SSA edge
- If dest is a ϕ-function, **Visit-ϕ**

SCC Algorithm: Processing *SWL* Item

- Item is SSA edge
- If dest is a ϕ-function, **Visit-ϕ**
- If dest is an expression and any of *ExecutableFlag*s for the incoming flow graph edges of dest is true, perform **VisitExpression**

SCC Algorithm: Visit-ϕ

$$v = \phi(v_1, v_2, \ldots, v_k)$$

- If i^{th} incoming edge's *ExecutableFlag* is true, $val_i = \text{ValueOf}(v_i)$ else $val_i = \top$

SCC Algorithm: Visit-ϕ

$$v = \phi(v_1, v_2, \ldots, v_k)$$

- If i^{th} incoming edge's *ExecutableFlag* is true, $val_i = \text{ValueOf}(v_i)$ else $val_i = \top$
- $\text{ValueOf}(v) = \bigwedge_i val_i$

SCC Algorithm: VisitExpression

- Evaluate the expression using values of operands and rules for operators

SCC Algorithm: VisitExpression

- Evaluate the expression using values of operands and rules for operators
- If the result is same as old, nothing to do

SCC Algorithm: VisitExpression

- Evaluate the expression using values of operands and rules for operators
- If the result is same as old, nothing to do
- Otherwise

SCC Algorithm: VisitExpression

- Evaluate the expression using values of operands and rules for operators
- If the result is same as old, nothing to do
- Otherwise
  - If the expression is part of assignment, add all outgoing SSA edges to *SWL*

SCC Algorithm: VisitExpression

- Evaluate the expression using values of operands and rules for operators
- If the result is same as old, nothing to do
- Otherwise
  - If the expression is part of assignment, add all outgoing SSA edges to *SWL*
  - if the expression controls a conditional branch, then

SCC Algorithm: VisitExpression

- Evaluate the expression using values of operands and rules for operators
- If the result is same as old, nothing to do
- Otherwise
  - If the expression is part of assignment, add all outgoing SSA edges to *SWL*
  - if the expression controls a conditional branch, then
    - if the result is $\perp$, add all outgoing flow edges to *FWL*

SCC Algorithm: VisitExpression

- Evaluate the expression using values of operands and rules for operators
- If the result is same as old, nothing to do
- Otherwise
  - If the expression is part of assignment, add all outgoing SSA edges to *SWL*
  - if the expression controls a conditional branch, then
    - if the result is $\perp$, add all outgoing flow edges to *FWL*
    - if the value is constant *c*, only the corresponding flow graph edge is added to *FWL*

SCC Algorithm: VisitExpression

- Evaluate the expression using values of operands and rules for operators
- If the result is same as old, nothing to do
- Otherwise
  - If the expression is part of assignment, add all outgoing SSA edges to *SWL*
  - if the expression controls a conditional branch, then
    - if the result is $\bot$, add all outgoing flow edges to *FWL*
    - if the value is constant *c*, only the corresponding flow graph edge is added to *FWL*
    - Value can not be $\top$ (why?)

SCC Algorithm: Complexity

- Each SSA edge is examined twice

SCC Algorithm: Complexity

- Each SSA edge is examined twice
- Flow graph nodes are visited once for every incoming edge

SCC Algorithm: Complexity

- Each SSA edge is examined twice
- Flow graph nodes are visited once for every incoming edge
- Complexity = O(# of SSA edges + # of flow graph edges)

SCC Algorithm: Correctness and Precision

- SCC is conservative

SCC Algorithm: Correctness and Precision

- SCC is conservative
  - Never labels a variable value as a constant

SCC Algorithm: Correctness and Precision

- SCC is conservative
  - Never labels a variable value as a constant
- SCC is at least as powerful as Conditional Constant Propagation (CC)

SCC Algorithm: Correctness and Precision

- SCC is conservative
  - Never labels a variable value as a constant
- SCC is at least as powerful as Conditional Constant Propagation (CC)
  - Finds all constants as CC does

SCC Algorithm: Correctness and Precision

- SCC is conservative
  - Never labels a variable value as a constant
- SCC is at least as powerful as Conditional Constant Propagation (CC)
  - Finds all constants as CC does
- PROOFs: In paper **Constant propagation with conditional branches** by **Mark N. Wegman, F. Kenneth Zadeck**, ACM TOPLAS 1991.

Practice Example