Decompilation

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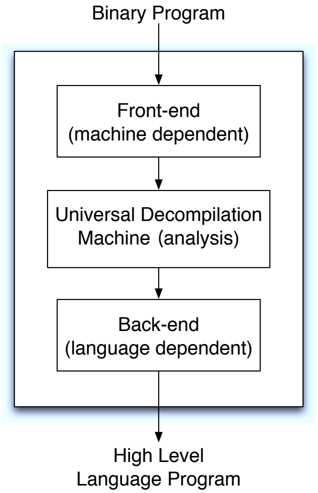
Decompiler Definition

- *Decompiler* is a program that attempts to perform the inverse process of the compiler.
- Given an executable program compiled in any high-level language, the aim is to produce a high-level language program that performs the same function as the executable program.
- *Input:* Machine dependent
- *Output:* Language dependent

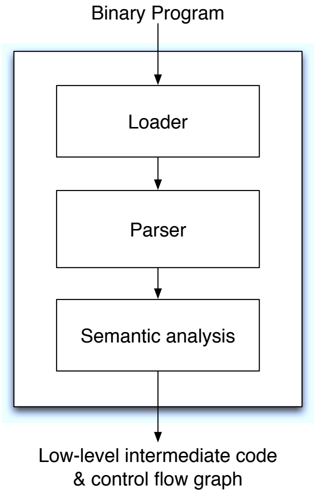
3 Main Modules of Decompiler


Binary Program
Front-end (machine dependent)
Universal Decompilation Machine (analysis)
Back-end (language dependent)
High Level Language Program

Front-end

- Deals with *machine-dependent* features and produces a *machine-independent* representation.
- Input: a binary program for a specific machine
- Produces:
  - Intermediate representation of the program
  - The program's control flow graph

Front-end Phases



Front-end Phases

- Loader: loads a binary program into virtual memory
- Parser:
  - Disassembles code starting at the entry point given by the loader.
  - Follows the instructions sequentially until a change in flow of control is met. All instruction paths are followed in a recursive manner.
  - The intermediate code is generated and the control flow graph is built.
- Semantic analysis: performs idiom analysis and type propagation.

Intermediate Code

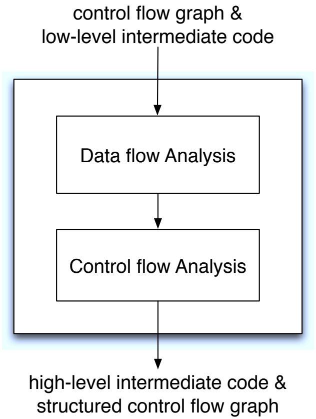
Two levels of intermediate code are required:

- A low-level representation that resembles the assembler from the machine: mapping of machine instructions to assembler mnemonics. — generated by front-end
- A higher-level representation that resembles statements from a high-level language — generated by the inter-procedural data flow analysis.

Universal Decompiling Machine

- The universal decompiling machine (UDM) is an intermediate module that is totally machine and language independent.
- It deals with flow graphs and the intermediate representation of the program and performs all the flow analysis the input program needs.

Universal Decompiling Machine Phases


control flow graph &
low-level intermediate code
Data flow Analysis
Control flow Analysis
high-level intermediate code &
structured control flow graph

Data Flow Analysis

- Transform the low-level intermediate representation into a higher-level representation that resembles a HLL statement.
- Eliminate the concept of condition codes (or flags) and registers, as these concepts do not exist in high-level languages.
- Introduce the concept of expressions and parameter passing, as these can be used in any HLL program.
  - `asgn` (assign)
  - `jcond` (conditional jump)
  - `jmp` (unconditional jump)
  - `call` (sub-routine call)
  - `ret` (sub-routine return)

Data Flow Analysis — HLCC

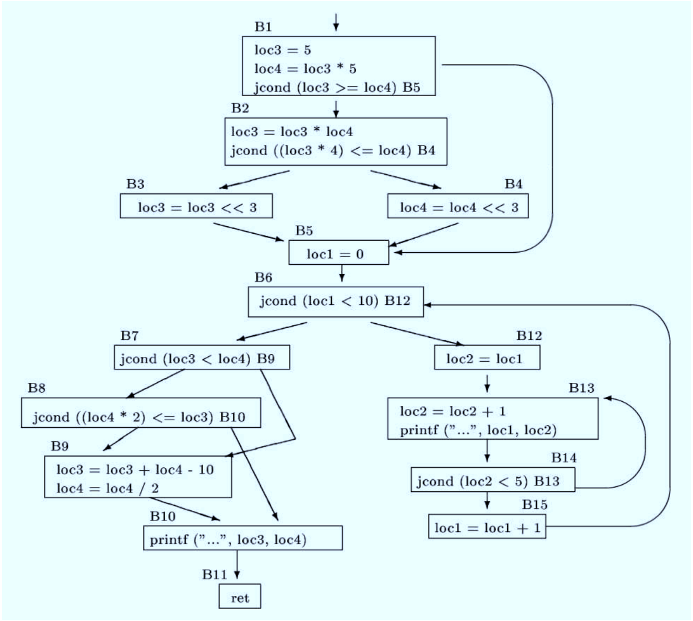
```
1 cmp ax, bx ; def: SF,ZF,CF
2 jp labZ    ; use: SF,ZF  ; ud-cc(SF,ZF)={1}
                 ⇓
          JCOND (ax > bx)
```

Data Flow Analysis — HLI

```
.. ...                  ; other code here
28 MOV   ax, di         ; ASGN ax, di         ; du(ax) = {30}
29 MOV   bx, 0Ah        ; ASGN bx, 0Ah        ; du(bx) = {32,33}
30 CWD                  ; ASGN dx:ax, ax      ; du(ax) = {31}, du(dx) = {31}
31 MOV   tmp, dx:ax     ; ASGN tmp, dx:ax     ; du(tmp) = {32,33}
32 DIV   bx             ; ASGN ax, tmp / bx ; du(ax) = {}
33 MOD   bx             ; ASGN dx, tmp % bx ; du(dx) = {34}
34 MOV   si, dx         ; ASGN si, dx
.. ...                  ; other code here, no use of ax
```

$$\Downarrow$$

```
ASGN si, di % 0Ah
```



B1
loc3 = 5
loc4 = loc3 * 5
jcond (loc3 >= loc4) B5
B2
loc3 = loc3 * loc4
jcond ((loc3 * 4) <= loc4) B4
B3
loc3 = loc3 << 3
B4
loc4 = loc4 << 3
B5
loc1 = 0
B6
jcond (loc1 < 10) B12
B7
jcond (loc3 < loc4) B9
B8
jcond ((loc4 * 2) <= loc3) B10
B9
loc3 = loc3 + loc4 - 10
loc4 = loc4 / 2
B10
printf ("...", loc3, loc4)
B11
ret
B12
loc2 = loc1
B13
loc2 = loc2 + 1
printf ("...", loc1, loc2)
B14
jcond (loc2 < 5) B13
B15
loc1 = loc1 + 1

Control Flow Analysis

High-level control structures:

- Loops
  - pre-test loop: `while()`
  - post-test loop: `repeat ...until()`
  - infinite loop: `loop`
- Conditionals
  - 2-way conditionals: `if ...then` and `if ...then ...else`
  - n-way conditionals: `case`

Control Flow Analysis

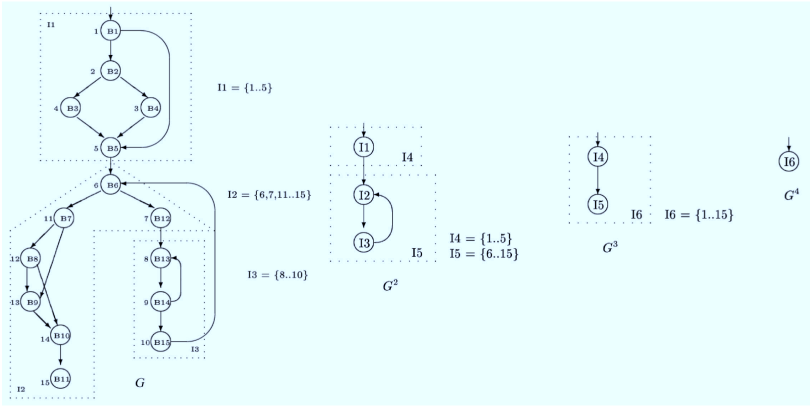
There are three types of nodes of subgraphs that represent high-level loops and 2-way structures:

- **Header node:** entry node of a structure.
- **Follow node:** the first node that is executed after a possibly nested structure has finished.
- **Latching node:** the last node in a loop; the one that takes as immediate successor the header of a loop.

Interval Theory

- By Interval theory, an interval $I(h)$ is the maximal, single-entry subgraph in which h is the only entry node and in which all closed paths contain h. The unique interval node h is called the header node. By selecting the proper set of header nodes, graph G can be partitioned into a unique set of disjoint interval $\mathcal{I} = \{I(h_1), I(h_2), \ldots, I(h_n)\}$
- The derived sequence of graphs, $G^1 \ldots g^n$ is based on the intervals of graph G. The first order graph, G^1, is G. The second order graph, G^2, is derived from G^1, by collapsing each interval in G^1 into a node.

Interval Theory



Structuring Loops

- Given an interval $I(h_j)$ with header h_j, there is a loop rooted at h_j if there is a back-edge to the header node h_j from a latching node $n_k \in I(h_j)$.
- Once a loop has been found, the type of loop is determined by the type of header and latching nodes of the loop.
    - A `while()` loop is characterized by a 2-way header node and a 1-way latching node.
    - A `repeat ...until()` is characterized by a 2-way latching node a non-conditional header node.
    - A endless `loop` loop is characterized by a 1-way latching node and a non-conditional header node.

Structuring Loops — Algorithm

1. Each header of an interval in G^1 is checked for having a back-edge from a latching node that belongs to the same interval.
2. If this happens, a loop has been found, so its type is determined, and the nodes that belong to it are **marked**.
3. Next, the intervals of G^2, $\mathcal{I}^2$ are checked for loops, and the process is repeated until intervals in $\mathcal{I}^n$ have been checked.

Structuring 2-Way Conditionals

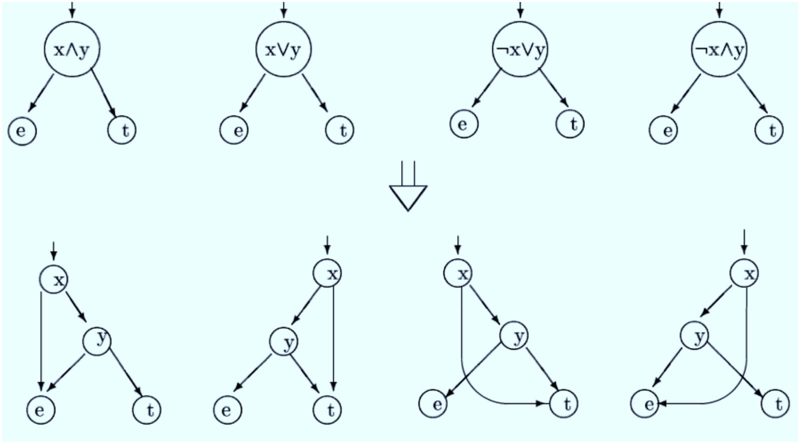
- Both a single branch conditional (i.e. `if ...then`) and an `if ...then ...else` conditional subgraph have a common follow node that has the property of being immediately dominated by the 2-way header node.
- When these subgraphs are nested, they can have different follow nodes or **share** the same common follow node.
- During loop structuring, a 2-way node that belongs to either the header or the latching node of a loop is marked as being part of the loop, and must therefore not be processed during 2-way conditional structuring.

Compound Conditions

Whenever a subgraph of the form of the short-circuit evaluated graphs is found, it is checked for the following properties:

1. Nodes `x` and `y` are 2-way nodes.
2. Node `y` has only 1 in-edge.
3. Node `y` has a unique instruction; a conditional jump (`jcond`) high-level instruction.
4. Nodes `x` and `y` must branch to a common `t` or `e` node.

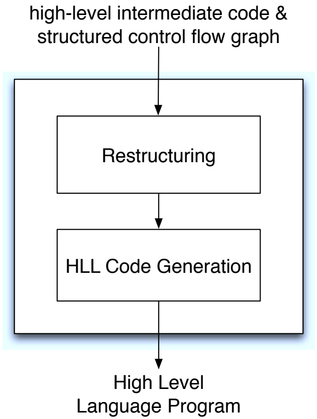
Compound Conditional Graphs



Back-end

- Restructuring (optional): structuring the graph even further, so that control structures available in the target language but not present in the generic set of control structures of the structuring algorithm, previously described, are utilized.
- HLL code generation: generates code for the target HLL based on the control flow graph and the associated high-level intermediate code. Involves:
  - Defines global variables.
  - Emits code for each procedure/function following a depth first traversal of the call graph of the program.
  - If a goto instruction is required, a unique label identifier is created and placed before the instruction that takes the label.
  - Variables and procedures are given names of the form `loc1`, `proc2`.

Back-end phases



The Decompiling System

- The decompiling system that integrates a decompiler, *dcc*, and an automatic signature generator, *dccSign*.
- A signature generator is a front-end module that generates signatures for compilers and library functions of those compilers.
  - Such signatures are stored in a database, and are accessed by *dcc* to check whether a subroutine is a library function or not, in which case, the function is not analyzed by *dcc*, but replaced by its library name (e.g. `printf()`).