CODE OBFUSCATION

ATTACK STRATEGIES

Roberto Giacobazzi

Dipartimento di Informatica
Università degli Studi di Verona
Italy

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The source

Most of the slides are taken from:

Surreptitious Software: Obfuscation, Watermarking, and Tamperproofing for Software Protection

Christian Collberg
Jasvir Nagra
ISBN-10: 0321549252
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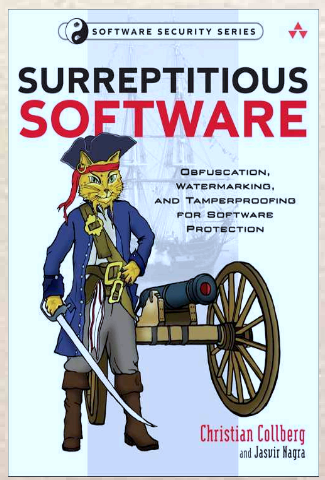
Addison-Wesley Professional 2010, 792 pp.



THE PROBLEM: PROTECTION

An attack typically goes through multiple phaes:

- The *black box* phase
- The *dynamic analysis* phase
- The *static analysis* phase
- The *editing* phase
- The *automation* phase

THE BLACK BOX PHASE

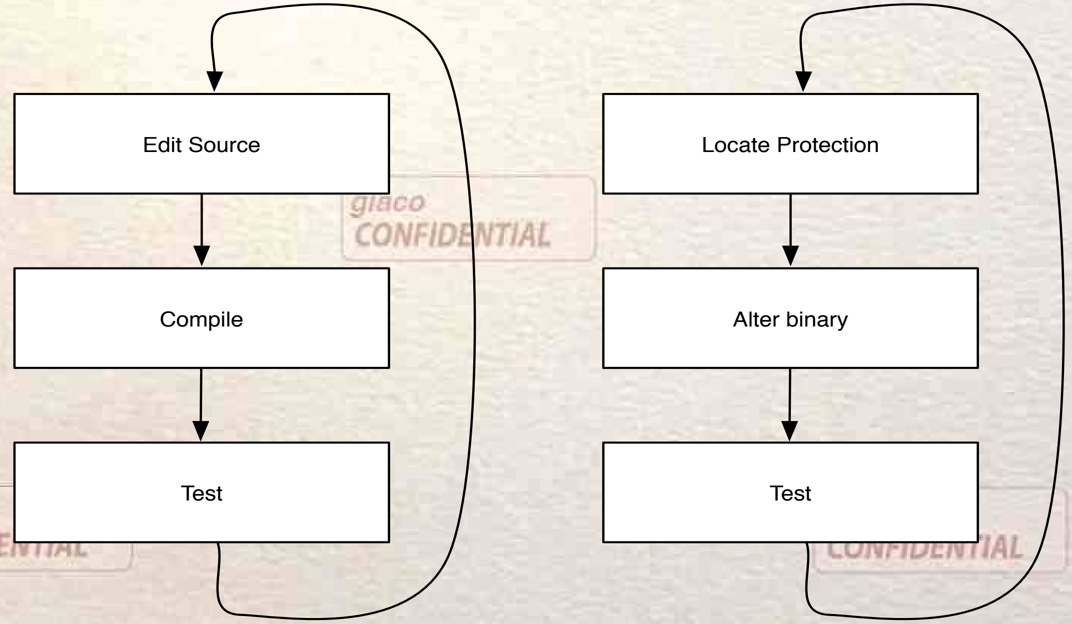
We feed the program with inputs and treat the program as an *oracle*

- Record the input/output behaviour
- Make a very first idea on the code behaviour
- In Architecture independent code (Java or C#) the black box phase can be locally applied to code portions
- Simple and obvious!!

THE DYNAMIC ANALYSIS PHASE

Code cracking is *almost* like code debugging

- There is indeed a difference:



- Locate the undesired behaviour (protection) then alter the behaviour (make it clean) and finally test it!

THE DYNAMIC ANALYSIS PHASE

Attacking protection mechanism and license check:

- Locate protection: e.g., *“Please enter your program activation code”*
- In Windows: set a breakpoint in `GetDlgItemInt()` that translates the input code into an integer
- Look up at the call stack to find the location of the user code that called the function: likely this will be close to the validity check)
- Deactivate the validity check
- Test the cracked program

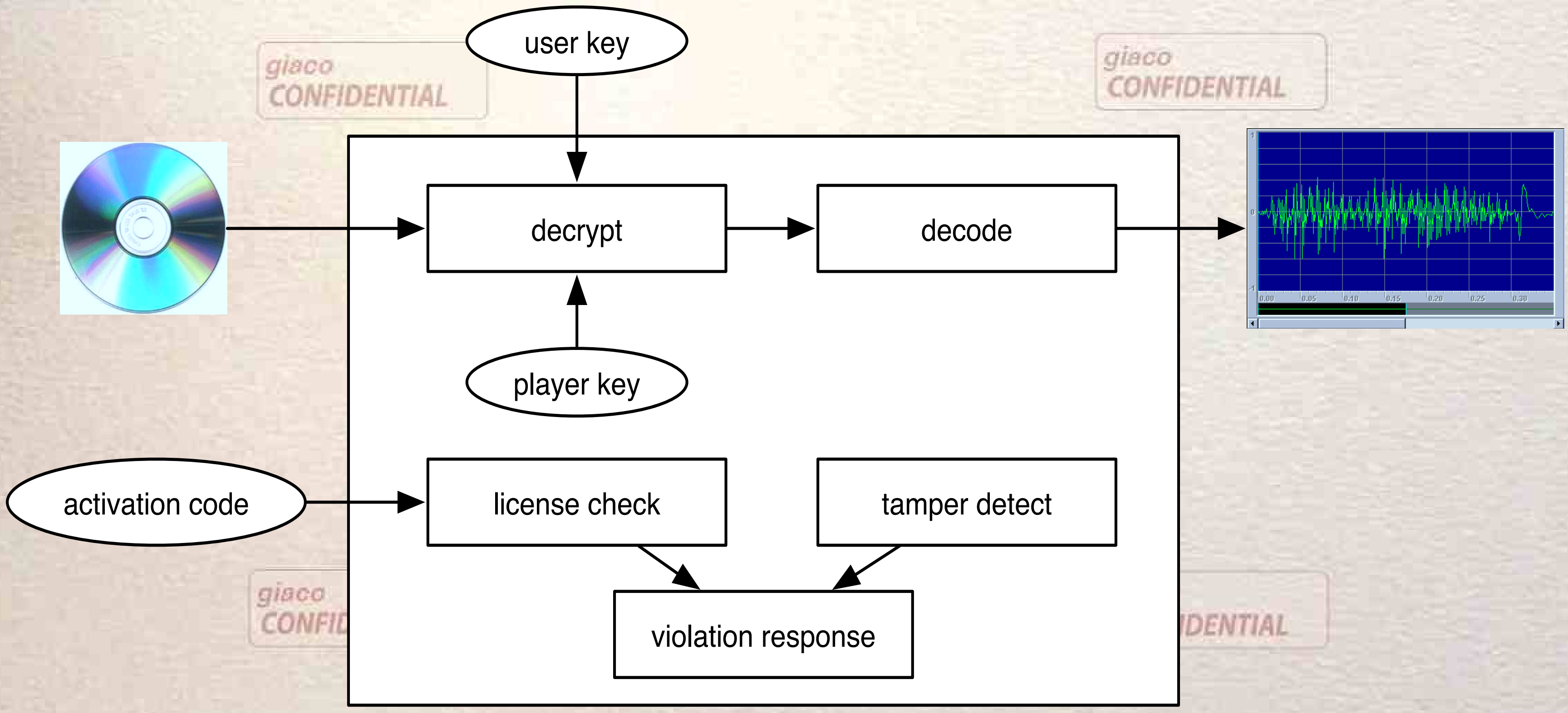
THE STATIC ANALYSIS PHASE

Essential tool to understand code structure and internal functionality:

- We need a disassembler
- We can derive the CFG
- We can derive information on live variables and their values
- We can derive the structure of the memory at a given program point

AN EXAMPLE: CRACKING A DRM SYSTEM

Essential tool to understand code structure and internal functionality:



DRM Player code

```
typedef unsigned int uint;
typedef uint* waddr_t;
uint player_key = 0xbabeca75;
uint the_key;
uint* key = &the_key;
FILE* audio;
int activation_code = 666

void FIRST_FUN(){}
uint hash (waddr_t addr, waddr_t last) {
  uint h = *addr;
  for (;addr <= last; addr++) h ^= *addr;
  return h;
}
void die (char* msg) {
  fprintf(stderr,"%s!\n",msg);
  key = NULL;
}
```

DRM PLAYER CODE II

```
uint play(uint user_key, uint encrypted_media[], int media_len) {
   int code;
   printf{"Please enter activation code:  ");
   scanf("%i", &code);
   if (code != activation_code) die("Wrong code");
   *key = user_key ^ player_key;
   int i;
   for (i=0; i<=media_len; i++) {
         uint decrypted = *key ^ encrypted_media[i];
         asm volatile (
             "jmp L1                       \n\t"
             ".align 4                     \n\t"
             ".long       0xb0b5b0b5\n\t"
             "L1:                          \n\t"
         );
         if (time(0) > 1221011472) die ("expired");
         float decoded = (float)decrypted;
         fprintf(audio,"%f\n",decoded); fflush(audio)
   }
}
```

DRM Player code II

```
void LAST_FUN(){}
uint player_main (uint argc, char *argv[])  {
      uint user_key = ............
      uint encrypted_media[100] = ............
      uint media_len = .............
      uint hashVal = hash((waddr_t)FIRST_FUN,(waddr_t)LAST_FUN);
      if (hashVal != HASH) die ("tampered");
      play(user_key, encrypted_media, media_len);
}
```

ATTACKING THE DRM PLAYER

Learning about the executable by standard OS primitives:

```
> file player
player: ELF 64-bits LSB executable, dynamically linked

> objdump - T player
DYNAMIC SYMBOL TABLE
0xa4   scanf
0x90   fprintf
0x12   time

> objdump - f player | grep start
start address 0x4006a0
}
```

Attacking the DRM Player: Black box

Feeding the program with inputs:

```
> player 0xca7ca115 1 2 3 4
Please enter activation code: 42
expired!
segmentation fault
```

We know that the executable is stripped and dynamically linked!

- library functions by name
- check by calling `time()`
- ... there should be some code like: `if (time(0) >` value `) ...`
- set a breakpoint on `time(0)`, run the code and check who called it!

ATTACKING THE DRM PLAYER: DYNAMIC ANALYSIS

We use the gdb debugger:

```
> gdb -write -silent --args player 0xca7ca115 1000 2000 3000 4000
(gdb) break time
Breakpoint 1 at 0x400680
(gdb) run
Please enter activation code: 42
Breakpoint 1, 0x400680 in time()
(gdb) where 2
#0 0x400680 in time
#1 0x4008b6 in ??
(gdb) up
#1 0x4008b6 in ??
(gdb) disassemble $pc -5 $pc+7
0x4008b1 callq 0x400680
0x4008b6 cmp   $0x48x72810, %rax
0x4008bc jle   0x4008c8
```

Attacking the DRM Player: Dynamic analysis

We can patch the executable by replacing:

```
0x4008bc jle   0x4008c8
```

with:

```
0x4008bc jg    0x4008c8
```

The player does not say `expired!` but still says: `wrong code`

```
> player 0xca7ca115 1 2 3 4
tampered!
Please enter activation code: 99
wrong code!
Segmentation fault
```

Idea: Let us search for "`wrong code`" in the binary!!

ATTACKING THE DRM PLAYER

The code should look like:

```
addr1: .ascii "wrong code"
       .........
       cmp read-val,activation-code
       je  somewhere
addr2: move addr1,reg0
       call printf
```

ATTACKING THE DRM PLAYER

Search the data-segment of line `addr1` then search for an instruction that contains that address:

```
(gdb) find 0x400ba8,+0x84,"wrong code"
0x400be2
(gdb) find 0x4006a0,+0x4f8,0x400be2
0x400862
(gdb) disassemble 0x40085d 0x400867
0x40085d  cmp    %eax,%edx
0x40085f  je     0x40086b
0x400861  mov    $0x400be2,%edi
0x400866  callq  0x4007e0
```

Bingo! we can replace the conditional jump:

```
0x40085f  je     0x40086b
```

with an unconditional (always) jump:

```
0x40085f  jmp    0x40086b
```

ATTACKING THE DRM PLAYER: WATCHING MEM

Still crash due to access to illegal memory location (unix), e.g. dereferencing a NULL pointer:

```
> player 0xca7ca115 1 2 3 4
tampered!
Please enter activation code: 55
Segmentation fault
```

Look at what address is trying to load or write: Look into memory!

```
(gdb) run
Program received signal SIGSEGV
0x40087b in ?? ()
(gdb) disassemble 0x40086b 0x40087d
0x40086b  mov  0x2009ce(%rip),%eax #0x601240
0x400872  mov  0x2009c0(%rip),%edx #0x601238
0x400878  xor  -0x14(%rbp),%edx
0x40087b  mov  %edx,(%rax)
```

The code tries to write to an address loaded from `0x601240` with failure!

ATTACKING THE DRM PLAYER: WATCHING MEM

Watchpoint on `0x601240` :

```
(gdb) watch *0x601240
(gdb) run
Hardware watchpoint 2: *0x601240
Old value = 6296176
New value = 0

0x400811 in ?? ()

(gdb) disassemble 0x400806 0x400812
0x400806  movq    $0x0,0x200a2f(%rip) #0x601240
0x400811  leaveq
```

Setting `key = NULL` in `die()` forces insctruction at location `0x400806` to the location at `0x601240` to 0.

ATTACKING THE DRM PLAYER: TAMPERING AGAIN

We bypass the `key = NULL` by overwriting `NOP` (x86 opcode `0x90`) operations:

```
(gdb) set {unsigned char} 0x400806 = 0x90

(gdb) set {unsigned char} 0x400810 = 0x90
```

Test:

```
(gdb) disassemble 0x400806 0x400812
0x400806 nop
.....
0x400810 nop
0x400811 leaveq
```

code cracked!!!

Is Reversing Legal?

see: E. Eilam. Reversing, Secrets of reverse engineering, Wiley 2005

Trial: SEGA vs. ACCOLADE

- In 1990 SEGA released the *Genesis Console* with secret interface.
- ACCOLADE reverse engineered the Genesis interface, for producing his own games running on Genesis.
- In October 1991 SEGA put the question on court for *copyright infringement*: The copies made by ACCOLADE during reverse engineering process (intermediate copying) violated copyright laws.
- The court ruled in favor of ACCOLADE for:
  - ✔ The SW developed by ACCOLADE did not contain code from SEGA.
  - ✔ The opening of Genesis Console to the market opens the market itself.

Reverse Engineering is legal for interoperability!

IS REVERSING LEGAL?

see: The Digital Millenium Copyright Act (DMCA) 1988

- Interoperability
- Encryption research: allows researchers to circumvent copyright protection if protection interfere with the evaluation of the encryption technology
- Security Testing: copyright protection can be reversed and circumvented for the evaluation and improving of the security of a computer system
- Educational institutions and public libraries: copyright protection can be reversed and circumvented in order to evaluate if the content can be published
- Government investigation: ... of course!!
- Regulation: protection technologies may be circumvented for access regulation (minors etc.)
- Privacy Protection: protection mechanisms can be violated if the protected code includes (stolen) personal information

Code Attack

An attack typically goes through multiple phaes:

- The *black box* phase
- The *dynamic analysis* phase
- The *static analysis* phase
- The *editing* phase
- The *automation* phase

STATIC ANALYSIS

High-level structural information: We know how to do it!

Typical static analysis include:

- CFG genertaion
- Control Flow analysis
- Data-flow analysis
- Type based analysis
- Invariant generation by Abstract interpretation
- Model checking

DYNAMIC ANALYSIS

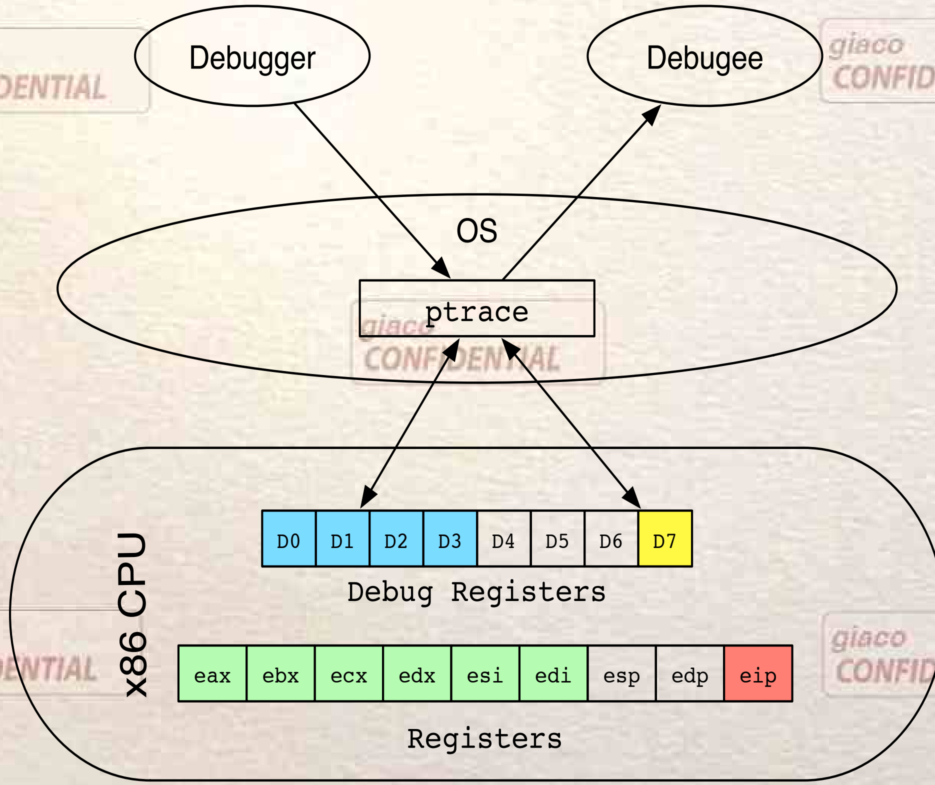
- Static analysis: extract properties that hold for all inputs (or input properties)
- Dynamic analysis: extract properties form the run of the program (under some selected input)

Typical dynamic analysis include:

- Debugging
- Profiling
- Tracing
- Emulation

DEBUGGING: SETTING BREAKPOINTS

We consider a *small Linux x86 Debugger* with HW and SW berakpoints, single stepping, print register and continue commands.



- `ptrace`: allows a parent process to observe and control another process: examine, modify registers, data, and text segments

DEBUGGING: USING ptrace

see: Linux Journal: Playing with ptrace, Part I, November 1st, 2002

```
#include <sys/ptrace.h>
#include <sys/types.h>
#include <sys/wait.h>
#include <unistd.h>
#include <linux/user.h>  int main()
{   pid_t child;
    long orig_eax;
    child = fork();
```

A process forks a child and the child executes the process we want to trace.

```
.....
}
```

Debugging: using ptrace

Before running `exec`, the child calls `ptrace` with the first argument, equal to PTRACE_TRACEME. This tells the kernel that the process is being traced, and when the child executes the `execve` system call, it hands over control to its parent. The parent waits for notification from the kernel with a `wait()` call. Then the parent can check the arguments of the system call or do other things, such as looking into the registers.

```
.....
    if(child == 0) {
        ptrace(PTRACE_TRACEME, 0, NULL, NULL);
        execl("/bin/ls", "ls", NULL);
    }
    else {
        wait(NULL);
        orig_eax = ptrace(PTRACE_PEEKUSER, child, 4 * ORIG_EAX,NULL);
        printf("The child made a system call %ld\n", orig_eax);
        ptrace(PTRACE_CONT, child, NULL, NULL);
    }
    return 0;
```

DEBUGGING: USING `ptrace`

Tracing system calls

- Fork a child process
- Signal the kernel that the process will be traced
- Make the system call
- Look into the register (`eax`)
- Continue

-
- `PTRACE_TRACEME`
-
- `PTRACE_PEEKUSER`
- `PTRACE_CONT`

THE DEBUGGER

Debug a debugee:

```
#include <sys/types.h>
#include <sys/ptrace.h>
#include <sys/wait.h>
#include <sys/reg.h>
#include <sys/user.h>
pid_t debugee_pid;
int status;
char *arg[] = {"debugee"};
debugee_pid = fork();
if (debugee_pid <0) error
else if (debugee_pid == 0 ) {
  int err=ptrace(PTRACE_TRACEME,0,NULL,NULL);
  execv("debugee", args);
} else {
  wait(&status);
  db_loop();
}
```

/* debugee_pid $= 0$
/* Child process:
control and exec debugee
/* debugee_pid > 0
/* Parent process:
wait and debug

THE DEBUGGER

```
void dbg_loop() {
  char op;
  uint32 arg;
  while (1) {
    dbg_parse(&op,&arg);
    switch (op) {
     case 'c':dbg_continue();break;
     case 'b':dbg_setSWBreakpoint(arg);break;
     case 'B':dbg_setHWBreakpoint(arg);break;
     case 'r':dbg_printRegs();break;
     case 's':dbg_step(arg);break;  }
   if (status==1407) {
    enum event e = dbg_getEvent();
    if (e==swBPhit) dbg_handleSWBreakpoint();
    else if (e==hwBPhit)
             dbg_handleHWBrealpoint();
    dbg_setDbgReg(6,0x0);
    }
  }
}
```

/* c continue
/* b arg set SW breakpoint at address arg
/* B arg set HW breakpoint at address arg
/* r print registers
/* s arg step arg instructions

The Debugger

```
void dbg_continue() {
   err = ptrace(PTRACE_CONT,debugee_pid,NULL,NULL);
   wait(&status)]
}
/* PTRACE_CONT: Restarts the stopped child process.

void dbg_step(int steps) {
  for (i=1;i<=steps;i++) {
    int err=ptrace(PTRACE_SINGLESTEP,debugee_pid,NULL,NULL);
    wait(&status);
    }
}
/* PTRACE_SINGLESTEP: Restarts the stopped child, but arranges for the
child to be stopped after execution of a single instruction.
```

The behaviour is largely hidden inside the `ptrace` system call!!

DEBUGGING: SETTING HW-BREAKPOINTS

- The x86 has 4 registers `D0,D1,D2,D3` for breakpoint address and `D7` for controlling the debugging registers:
- `D7=1` trigger when execution hits the byte in address `D0`
  `D7=0` turn off the breakpoint: back to single step

```
uint32 dbg_getDbgReg(int reg) {
  return ptrace(PTRACE_PEEKUSER,debugee_pid,
                offsetof(struct user,u_debugreg[reg]),NULL);
}

/* PTRACE_PEEKUSR: Reads a word at offset addr in the child's USER area,
which holds the registers and other information.
```

DEBUGGING: SETTING HW-BREAKPOINTS

- The x86 has 4 registers `D0,D1,D2,D3` for breakpoint address and `D7` for controlling the debugging registers:

- `D7=1` trigger when execution hits the byte in address `D0`
  `D7=0` turn off the breakpoint: back to single step

```
void dbg_setDbgReg(int reg, uint32 val) {
  int err=ptrace(PTRACE_POKEUSER,debugee_pid,
                 offsetof(struct user,u_debugreg[reg]), val);
}

/* PTRACE_POKEUSR: Copies the word data to offset addr in the child's
USER area.
```

DEBUGGING: SETTING HW-BREAKPOINTS

- The x86 has 4 registers D0,D1,D2,D3 for breakpoint address and D7 for controlling the debugging registers:
- D7=1 trigger when execution hits the byte in address D0
  D7=0 turn off the breakpoint: back to single step

```
void dbg_setHWBreakpoint(uint32 addr) {
  dbg_setDbReg(0, addr);
  dbg_setDbReg(7, 0x1);
}

void dbg_handleHWBreakpoint(uint32 addr) {
  dbg_setDbReg(7, 0x0);
  dbg_step(1);
  dbg_setDbReg(7, 0x1);
}
```

Debugging: setting Memory-watchpoints

- The x86 has only 4 registers `D0,D1,D2,D3` for breakpoint address. So we can only monitor 4 memory words:

```
void dbg_getRegs(struct user_regs_struct* regs) {
  int err = ptrace(PTRACE_GETREGS, debugee_pid, NULL, regs)
}
/* PTRACE_GETREGS: Copies the child's general purpose to location
data in the parent.

void dbg_setRegs(struct user_regs_struct* regs) {
  int err = ptrace(PTRACE_SETREGS, debugee_pid, NULL, regs)
}
/* PTRACE_SETREGS: Copies the child's general purpose registers
from location data in the parent.
```

DEBUGGING: SETTING MEMORY-WATCHPOINTS

- The x86 has only 4 registers D0,D1,D2,D3 for breakpoint address. so we can only monitor 4 memory words:

```
void dbg_printRegs() {
  struct user_regs_struct regs;
  dbg_getRegs(&regs);
  printf("edp=0x%x,esp=0x%x,eax=0x%x,ebx=0x%x,ecx=0x%x,edx=0x%x\n",
           regs.edp,regs.esp,regs.eax,regs.ebx,regs.ecx,regs.edx);
}
```

DEBUGGING: SETTING SW-BREAKPOINTS

- Idea: replace the instructions at the breakpoint address with one that will generate a signal giving control back to the debugger

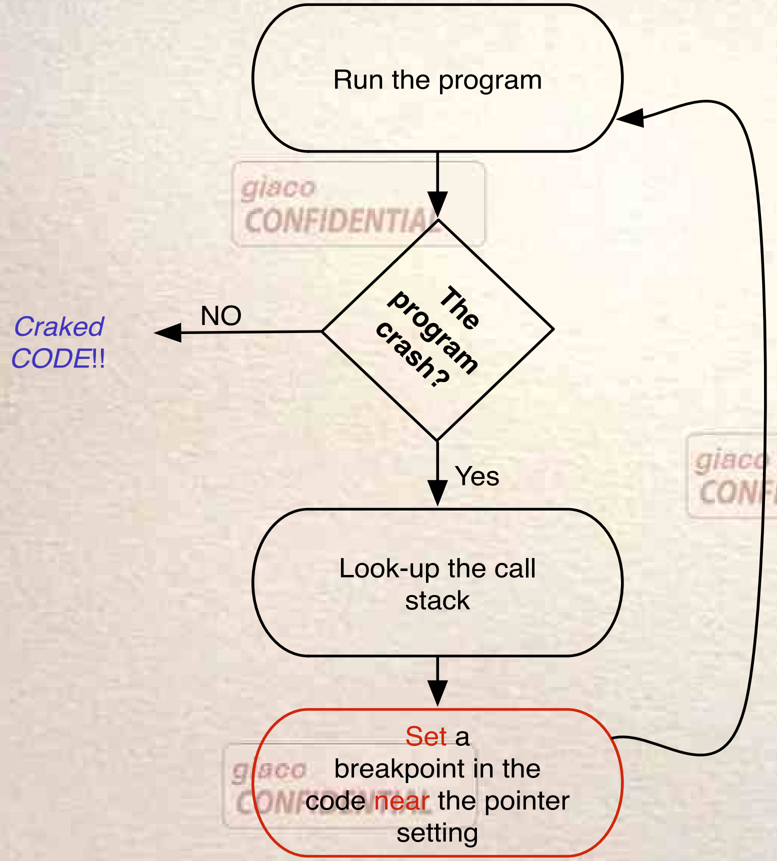
```
uint32 dbg_readText(uint32 addr) {
  return ptrace(PTRACE_PEEKTEXT,debugee_pid,addr,NULL);
}
void dbg_writeText(uint32 addr, uint32 instr) {
  return ptrace(PTRACE_POKETEXT,debugee_pid,addr,NULL);
}
uint32 origInstr, trapInstr swBPAddr;
void dbg_setSWBreakpoint(uint32 addr) {
  swBPAddr = addr;
  trapInstr = origInstr = dbg_readText(swBPAddr);
  ((char*) &trapInstr[0] = 0xCC; /*int 3
  dbg_writeText(swBPAddr,trapInstr);
}
```

DEBUGGING: SETTING SW-BREAKPOINTS

- Idea: when the breakpoint is hit: restore the original instruction, single step on it and restore the breakpoint for future use.

```
int dbg_handleSWBreakpoint() {
  struct user_reg_struct regs;
  dbg_getRegs(&regs);
  dbg_writeText(swBPAddr, origInstr);
  regs.eip--;
  dbg_setRegs(&regs);
  dbg_step(1);
  dbg_writeText(swBPAddr, trapInstr);
}
```

Reverse debugging



Removing a license check
... and tamperproofing

Time consuming!!
...we need backward execution!

Can we run backward until we find the location that has affected the value of variable X?
Idea: Backward watchpoint

REVERSE DEBUGGING

see: B. Boothe. Efficient algorithm for bidirectional debugging, ACM PLDI 2000.

```
long step_cnt = 0;
lont sc_stop_val = -1;

void step() {
  step_cnt++;
  if (step_cnt == sc_stop_val)
```
trap to the debugger
```
}
int call_depth = 0;

void enter() {call_depth++;}
void leave() {call_depth--;}
```

The algorithm is counter based!

- Counter `step_cnt` for every source line executed
- Keep track of the depth of call-stack: `enter` and `leave` inc/dec `call_depth`

Reverse debugging

Example: execute `proc(2)`

```
0  int proc(int x) {
1  enter();                int R,L;
2  STEP[2]();              int k=0;
3  STEP[3]();              while (k < x) {
4  STEP[4]();                 R = foo(k);
5  STEP[5]();                 L = L+R;
6  STEP[6]();                 k++; }
7  STEP[7]();leave(); return L;
8  }
9
10 int foo(int w) {
11 enter();                int R;
12 STEP[12]();             R = 2*W;
13 STEP[13]();leave();return R
14 }
}
```

step_cnt	line	call_depth
1	2	1
2	3	1
3	4	1
4	12	2
5	13	3
6	5	1
7	6	1
8	4	1
9	12	2
10	13	2
11	5	1
12	6	1
13	7	1

Reverse debugging

Example: setting a breakpoint at line n

```
int brkpt_cnt = 0;
long bc_stop_val = -1;

void brkpt() {
  step_cnt++;
  brkpt_cnt++;
  if (brkpt_cnt == bc_stop_val ||
     step_cnt == sc_stop_val)
```

trap to the debugger

```
}
void dbg_set_breakpoint(int line) {STEP[line] = brkpt;}
void dbg_clear_breakpoint(int line) {STEP[line] = step;}
void dbg_continue(int n) {bc_stop_val = brkpt_cnt + n;}
void dbg_bcontinue(int n) {bc_stop_val = brkpt_cnt - n;}
```

Replace the call to `step()` at line n with a call to `brkpt()`

Reverse debugging

Example: `continue` e `bcontinue`

```
int brkpt_cnt = 0;
long bc_stop_val = -1;

void brkpt() {
  step_cnt++;
  brkpt_cnt++;
  if (brkpt_cnt == bc_stop_val ||
      step_cnt == sc_stop_val)
```

trap to the debugger

```
}
void dbg_set_breakpoint(int line) {STEP[line] = brkpt;}
void dbg_clear_breakpoint(int line) {STEP[line] = step;}
void dbg_continue(int n) {bc_stop_val = brkpt_cnt + n;}
void dbg_bcontinue(int n) {bc_stop_val = brkpt_cnt - n;}
```

In `bcontinue` re-execute the program: it will stop at n^{th} previous breakpoint

Profiling

The profine of the execution of a program P is a record of the number of times its different parts have executed.

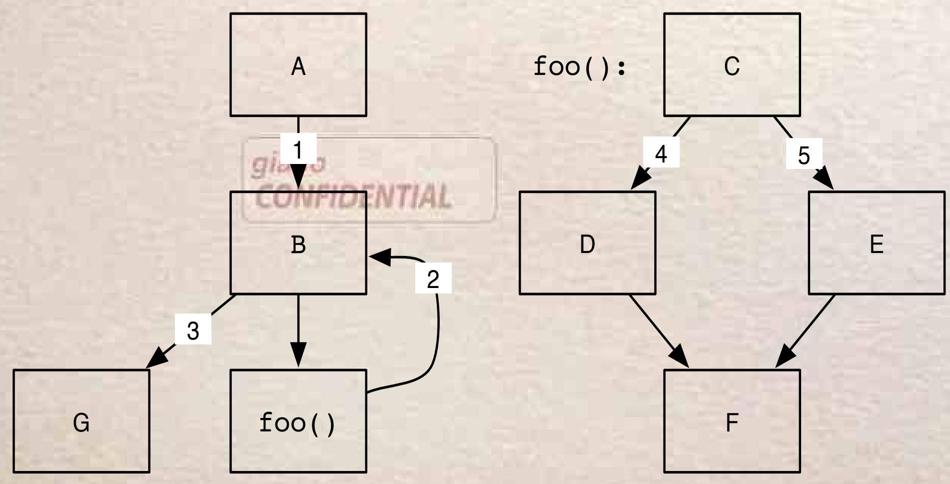
- *Frequency spectrum analysis*: execution count for program parts (e.g., functions, slices, eges in CFG etc.): function `foo()` is called 2345 times as well as function `baz()`
- Idea: Instrument the code, i.e., add code that allows us to count the use of relevant structures: $\mathcal{I} : Program \longrightarrow Program$

```
1. Input P;
2. Choose program input x;
3. Run the instrumented code I(P)(x);
4. Collect count-log for x and P in C_x;
5. goto 2 until φ is satisfied
6. Make statistics out of {C_x1,...,C_xn}
```

Tracing a program P is collecting blocks (and instructions) truly executed.

- **Problem:** Huge size of traces!
- **Idea:** Compress traces of P into a CFG G: the Directed Acyclic Graph (DAG) of G is called *Whole-Program Path*, WPP of P.

Consider the trace: 1424252525252523:



CFG:

$$\begin{cases} S \rightarrow 1AACCB3 \\ A \rightarrow 42 \\ B \rightarrow 52 \\ C \rightarrow BB \end{cases}$$

Tracing a program P is collecting blocks (and instructions) truly executed.

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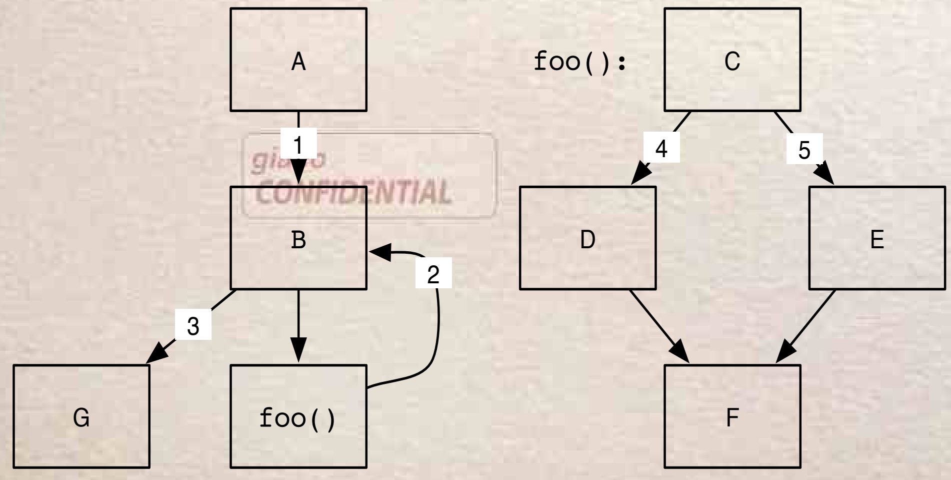
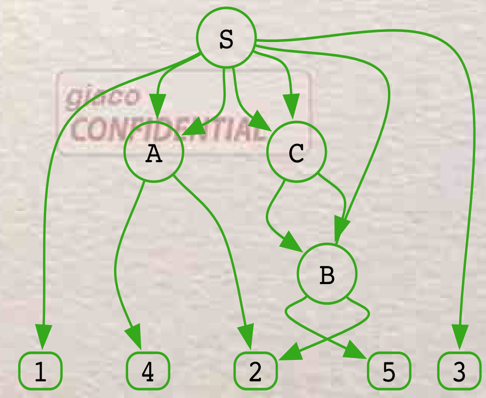
- Idea: Compress traces of P into a CFG G: the Directed Acyclic Graph (DAG) of G is called *Whole-Program Path*, WPP of P.

Consider the trace: 1424252525252523:



WPP:



TRACING

Algorithm SEQUITUR: *C.G. Nevill-Manning & I.H. Witter, 1997.* `http://sequitur.info/`

input: Trace T;

1. Create a CFG grammar with $Start := S \rightarrow \varepsilon$ and $G = \{Start\}$;
2. $c :=$ hd(T);
3. $Start := Start :: c$;
4. If $P \in G$ and digram DD is twice in P: $G := G[DD/R] \cup \{R \rightarrow DD\}$; (π_1)
5. If $R \rightarrow \gamma \in G$ and R is only used once in G: $G := G[R/\gamma] \setminus \{R \rightarrow \gamma\}$; (π_2)
6. goto 4 until $\pi_1 \wedge \pi_2$ hold;
7. goto 2 until $T = \varnothing$

return: CFG G;

Invariant:

π_1: no digram (pair of adjacent symbols) appears more than once

π_2: every rule is useful

TRACING

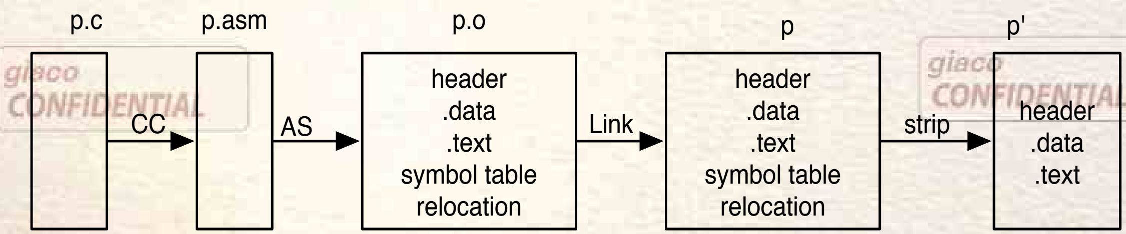
Compressing trace $T =$ abababababababa:

Result:

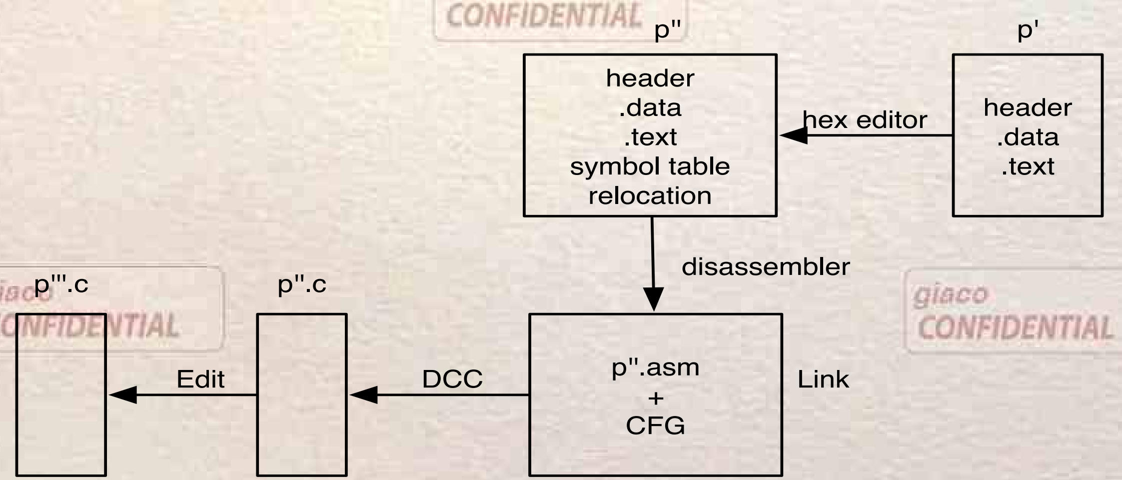
Rule	Expansion
S -> 0 -> 1 1 1 a \n	
1 -> 2 2	abab
2 -> a b	ab

Reconstructing Source

The typical development cycle:



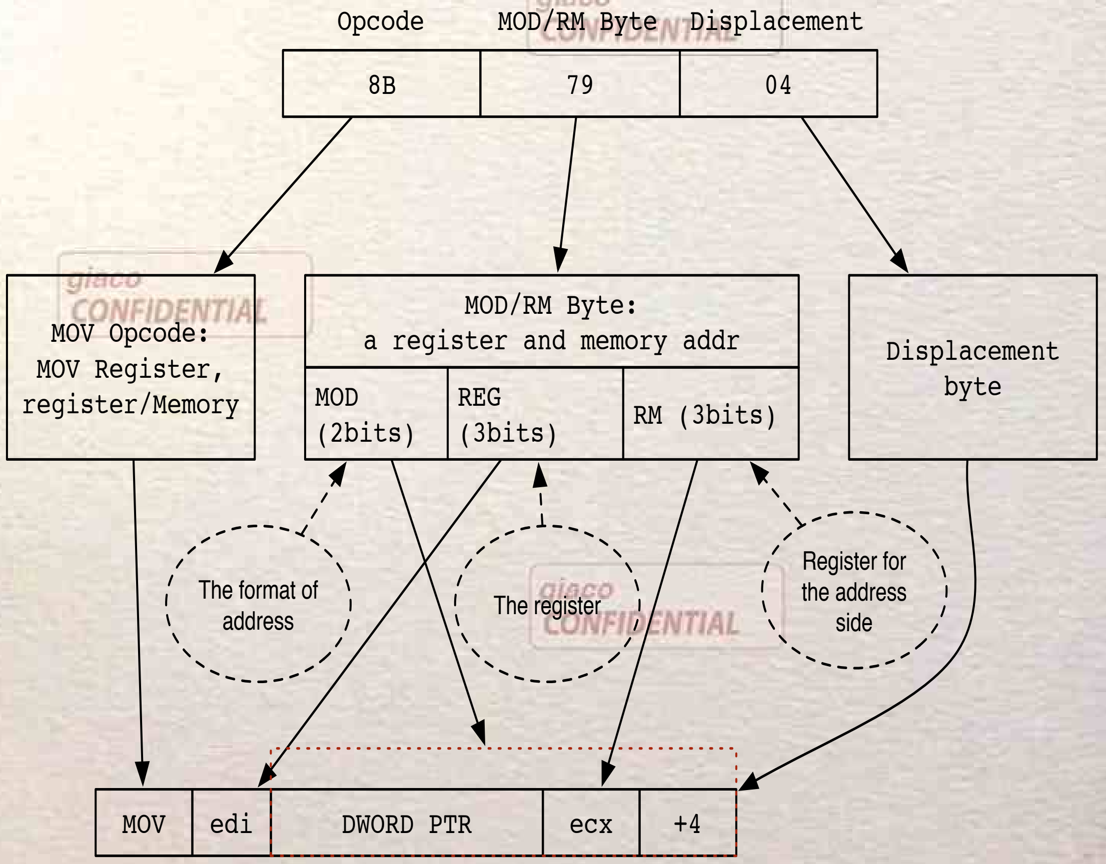
and its inverse:



DISASSEMBLY

The disassembled is a kind of compiler: Let us see how translation of an IA-32 instruction works!

- Opcode translation table
- Format translation table
- Code-symbol converter



Disassembly: Opcode translation

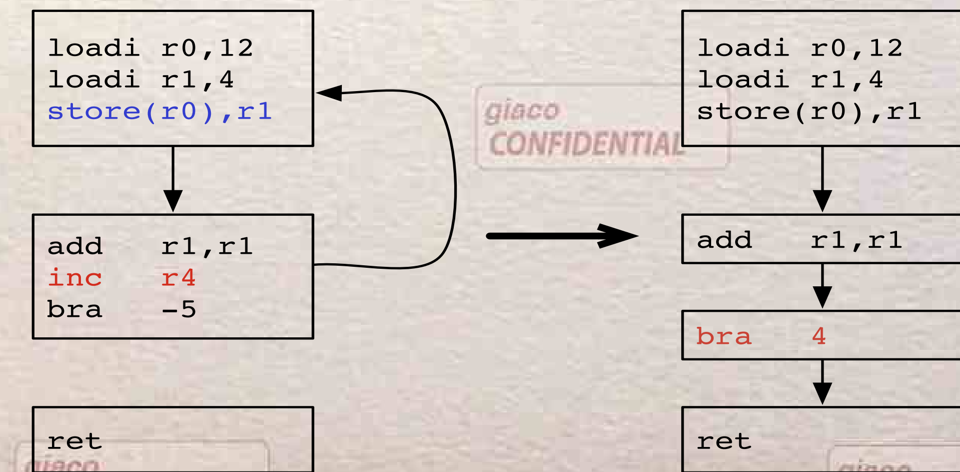
Opcode	Mnemonic	Operands	Semantics
0	`call`	$addr$	function call to $addr$
1	`calli`	reg	function call to address in reg
2	`brg`	$offset$	branch to pc $+$ $offset$ if flag for $>$ is set
3	`inc`	reg	increment reg
4	`bra`	$offset$	branch to pc $+$ $offset$
5	`jmpi`	reg	jump to address in reg
6	`prologue`		beginning of a function
7	`ret`		return from function
8	`load`	reg_1, (reg_2)	the content pointed to reg_2 goes into reg_1
9	`loadi`	reg, imm	the value imm goes into reg
10	`cmpi`	reg, imm	compare reg and imm and set flag
11	`add`	reg_1, reg_2	the sum of reg_1 and reg_2 goes into reg_1
12	`brge`	$offset$	branch to pc $+$ $offset$ if flag $\geq$
13	`breq`	$offset$	branch to pc $+$ $offset$ if flag $=$
14	`store`	(reg_1), reg_2	the value in reg_2 is stored in address inreg_1

DISASSEMBLY: OPCODE TRANSLATION

Address	Binary	Mnemonic	Operands
0:	[9,0,12]	loadi	r0,12
3:	[9,1,4]	loadi	r1,4
6:	[14,0,1]	store	(r0),r1
9:	[11,1,1]	add	r1,r1
11:	[3,4]	inc	r4
14:	[4,-5]	bra	-5
15:	[7]	ret	

Code and data are mixed!!!

Conde may change



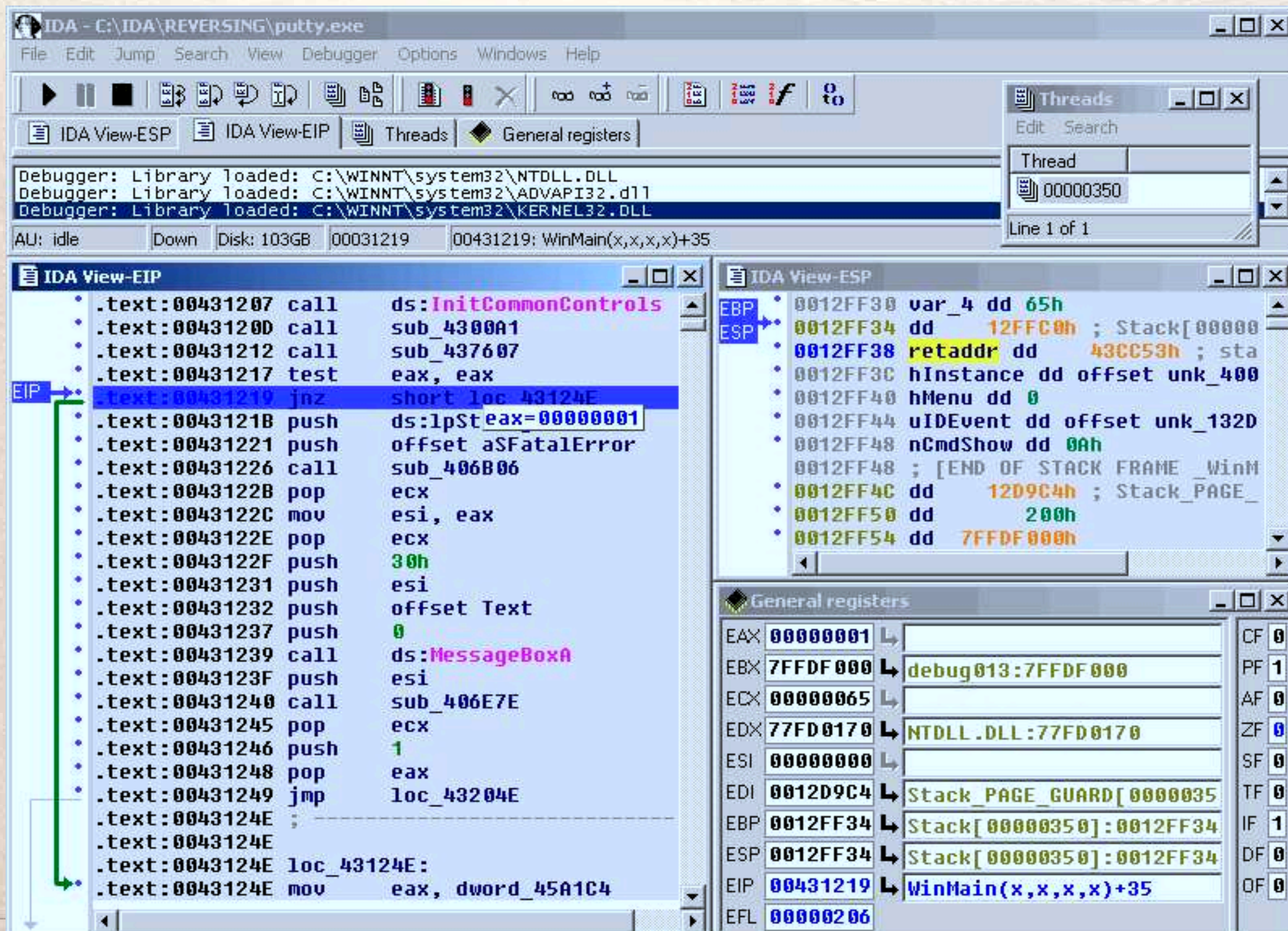
DISASSEMBLY

Some good disassemblers (for Microsoft platforms):

- Most debuggers include a disassembler, OllyDbg: `http://www.ollydbg.de/`
- PVDasm: is a Free, Interactive, Multi-CPU disassembler: `http://pvdasm.reverse-engineering.net/`
- IDA-Pro: Interactive disassembler by `www.datarescue.com` works for: IA-32, IA-64 (Itanium), AMD64 etc. and supports: PE (windows), ELF (Linux), and XBE (XBOX)
- ILDasm: for Microsoft intermediate language (MSL)

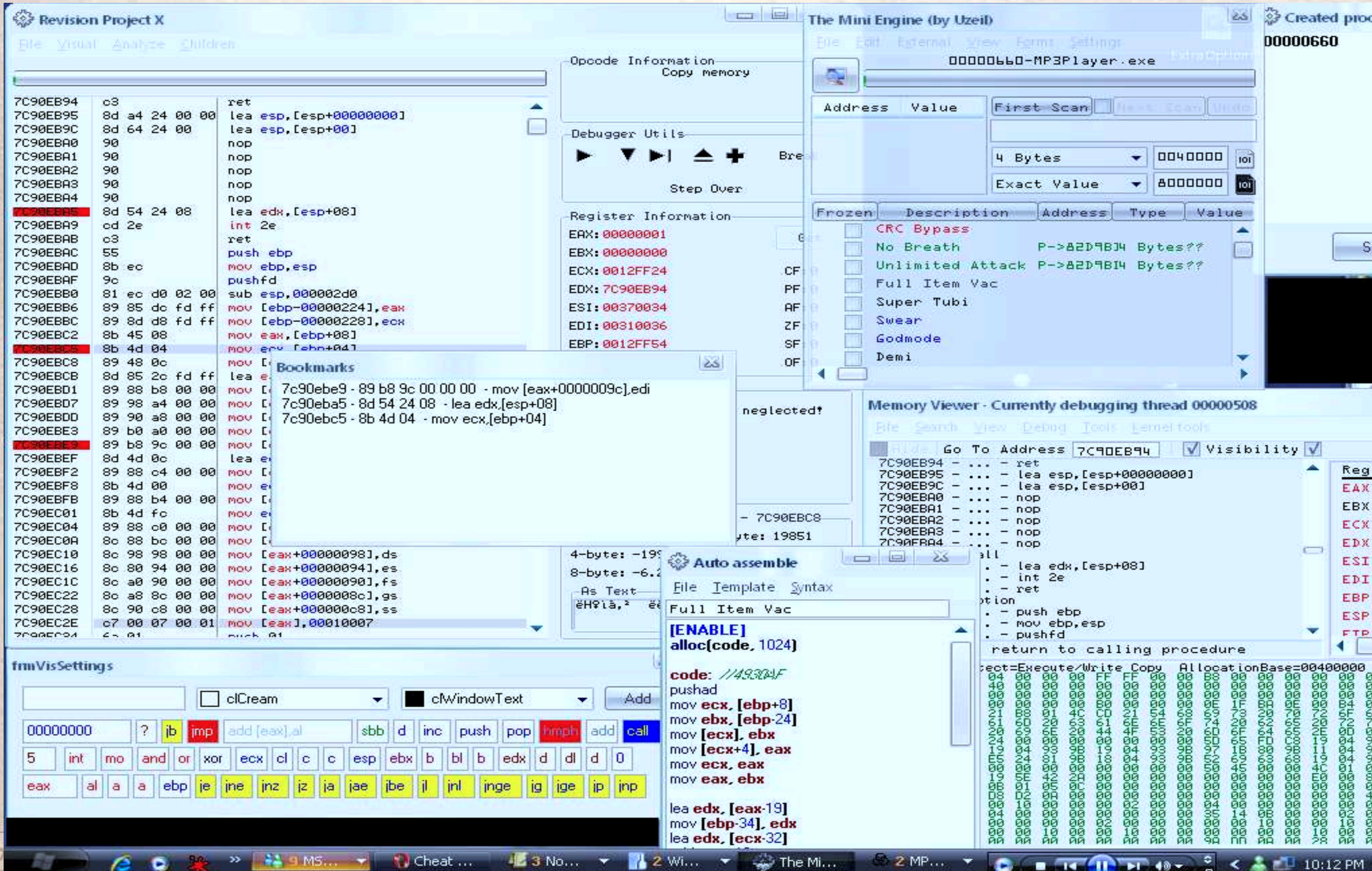
DISASSEMBLY AND DEBUGGER

The two work together (interactively!): IDA-Pro



DISASSEMBLY AND DEBUGGER

The two work together (interactively!):



DISASSEMBLY

We consider disassembly stripped binary (the harder problem):

see: DIABLO, *http://diablo.elis.ugent.be/*

- Static Disassembly: the file is examined by the disassembler but it is not executed
  - Advantage: processes the entire file at once
  - Time is proportional to the size of the program
- Dynamic Disassembly: monitor the execution of the file on some inputs in order to disassemble only the instructions that are executed
  - Disassembles a slice of the program
  - Time is proportional to the number of executed instructions (much bigger)

DISASSEMBLY

We consider disassembly stripped binary (the harder problem):

see: DIABLO, *http://diablo.elis.ugent.be/*

Static Disassembly: why so hard?

- In variable length instruction sets, instructions may overlap
- Data is commonly mixed with instructions
- Hard to determine the target of jumps
- Hard to find the beginning of functions with indirect call
- Hard to find the end of a function without `return`
- Hand-written assembly may be different from standard compile-time generated assembly
- Aggressive code compression may destroy code structure (overlapping functions)
- Extremely hard for self-modifying code.

Two main algorithmic approaches

- Linear Sweep: begins the disassemply at the inputâĂŹs program entry point and sweeps through the entire text section
  - Main weakeness: miss-interpretation of data embedded in the instruction stream
- Recursive Traversal: takes into account the control flow of the file to disassemble by determining the control flow successors of each branch instruction (not always possible/easy)

DISASSEMBLY: LINEAR SWEAP

The problem is that data in the `text` segment will be interpreted as code (wrong!!)

```
uint32 startAddr, endAddr;

void DisLinear(uint32 addr) {
  while (startAddr <= addr <= endAddr) {
         I = decode instruction at addr;
         addr = addr + length(I);
}}

void main()
{
  ep = program entry point;
  size = text section size;
  startAddr = ep;
  endAddr = ep + size;
  DisLinear(ep);
}
```

DISASSEMBLY: RECURSIVE TRAVERSAL

recursively follows the branches: you need to correctly catch the targets!!!

```
uint32  startAddr, endAddr;

void DisRecursive(uint32  addr) {
  while (startAddr <= addr <= endAddr) {
         if (addr has been visited already) return;
         I = decode instruction @ addr;
         mark addr as visited;
         if (I is a branch instruction)
                  for each possible target t of I do
                        DisRecursive(t);
                  return
         else addr = addr + length(I);
}}
```

DECOMPILATION

The decompiler translates the CFG into an *Abstract Syntax Tree (AST)* isomorphic to a high-level language structured (`if, while, for, repeat`) of sequences of assignements:

- Basic blocks: sequences of assignements
- CFG structure: basic iteration and conditional structures
- Typically includes its own disassembler (with its own problems!)

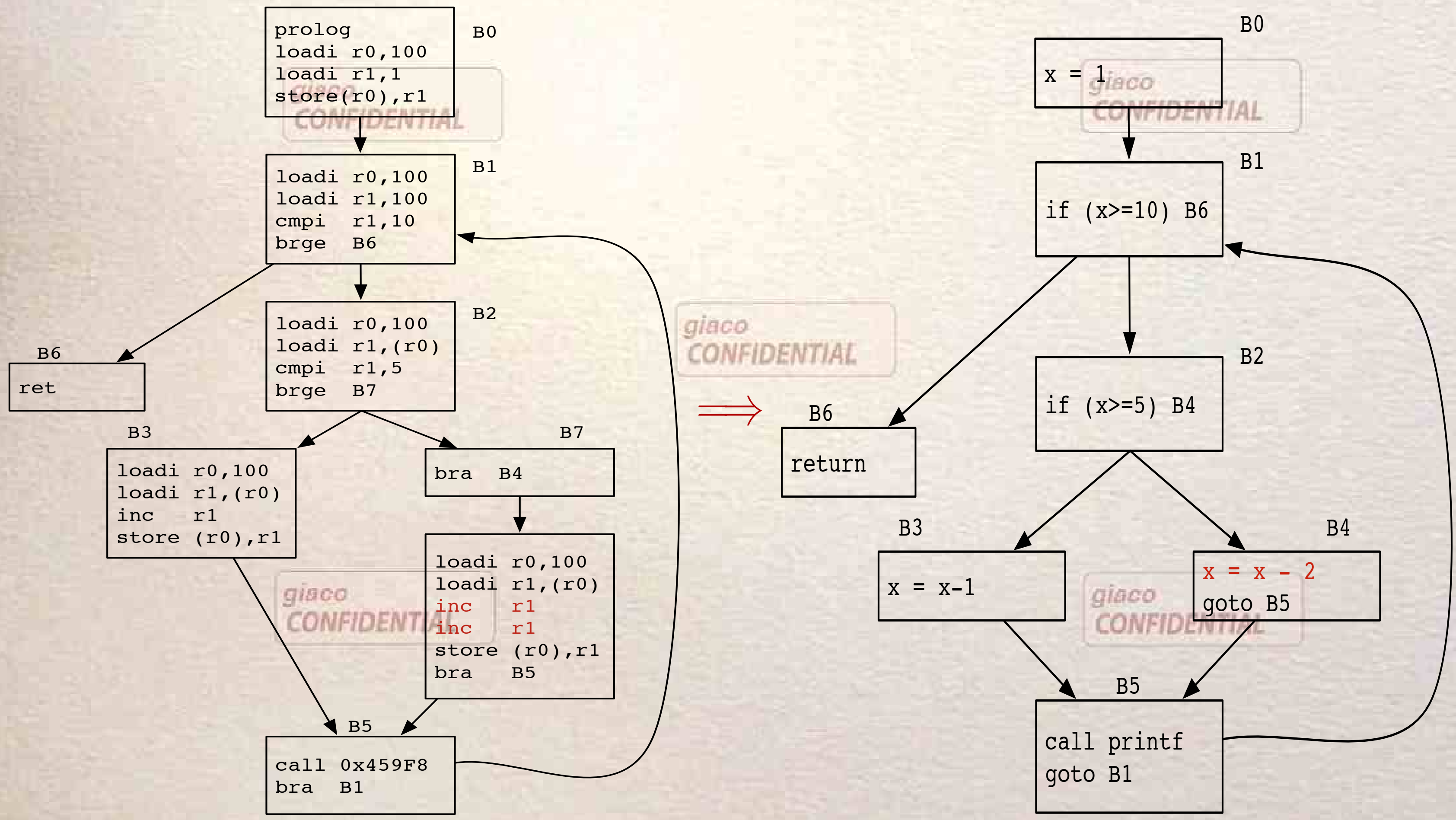
DECOMPILATION

What is hard in decompilation?

- Mismatch between legal assembly code and high-level control structures: (es `goto` in JavaBytecode but not in Java)
- Identify the call to library functions
- Identify idioms of different compilers
- Remove machine dependent artifacts
- Undo compiler optimizations (e.g., loop unrolling)

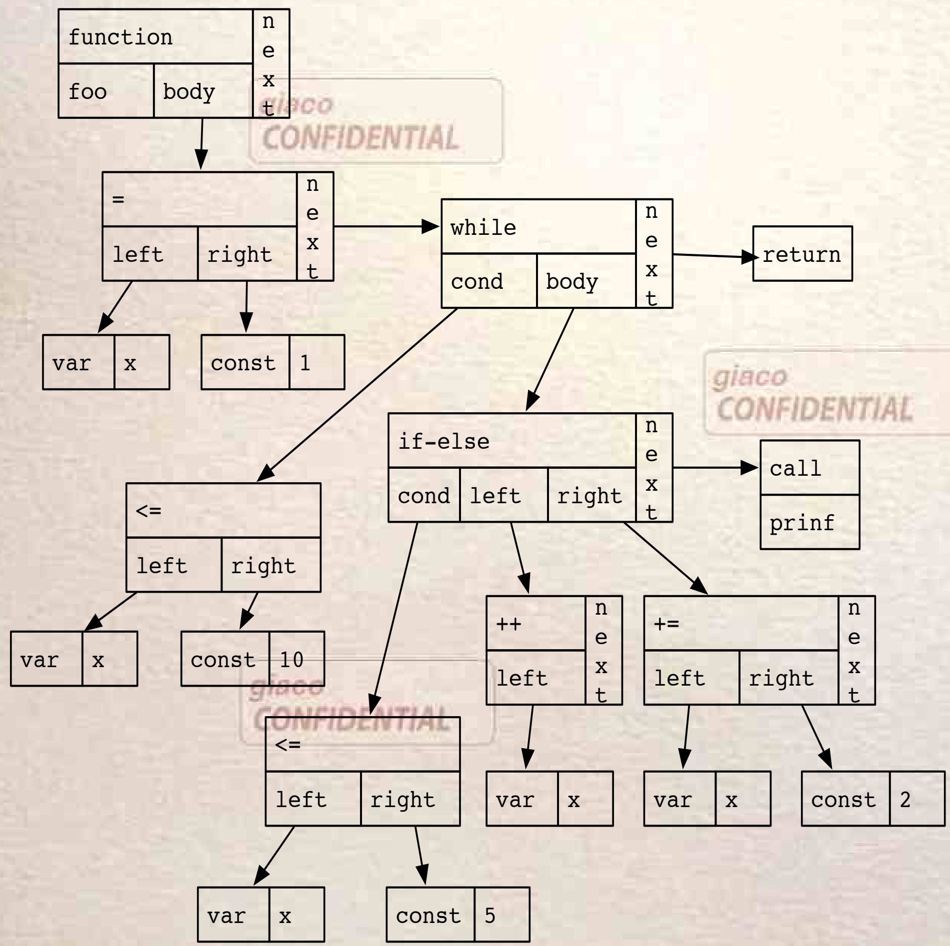
DECOMPILATION I

Example:



Decompilation II

Example:



AST

$\Longrightarrow$

```
void foo() {
  x=1;
  while (x<=10) {
      if (x<5)
          x ++;
      else
        x+=2;
      printf();
      }
}
```

DECOMPILATION: RECOVERING CONTROL FLOW

C. Cifuentes and K.J. Gough. Decompilation of binary programs, 1995 :

- Use of a database of *signature* for compilers
- Use of Data-flow analysis: *reaching definitions*

Input: X stripped executable

- ✔ Parse X distinguishing between `code-text` and `data`
- ✔ Determine the compiler by checking *signatures*
- ✔ Disassemble the `text` and generate a call graph G
- ✔ Remove from G functions that match the signaures
- ✔ Replace known idioms with high-level costructs
- ✔ Optimize G by removing jump-to-jumps
- ✔ RECOVERSTATEMENTS(G)
- ✔ Classify nodes by RESTRUCTURELOOPS(G) and RESTRUCTUREIFS(G)
- ✔ Traverse G and build the AST: for each block which is *head of control structure* traverse his body *depth-first* until the next node
- ✔ Traverse the AST and emit the source code

DECOMPILATION: RECOVERSTATEMENTS(G)

- For each Basic Block in G:
  - Perform reaching definitions on condition code and replace machine code tests and branches with `if-goto`:

$$\begin{array}{lll} i: & \texttt{cmpi} & r, imm \\ & \downarrow & \\ j: & \texttt{brg} & \texttt{lab} \end{array} \Rightarrow \quad j: \quad \texttt{if}\ r > imm\ \texttt{goto lab}$$

  - Perform reaching definitions live interprocedural register analysis and replace temporary registers tmp with its symbolic contents where used:

$$\begin{array}{lll} i: & \texttt{add} & tmp, v \\ & \downarrow & \\ j: & \texttt{cmpi} & tmp, imm \end{array} \Rightarrow \quad j: \quad \texttt{cmpi}\ tmp + v, imm$$

  - Replace calls to library functions with corresponding symbolic calls:

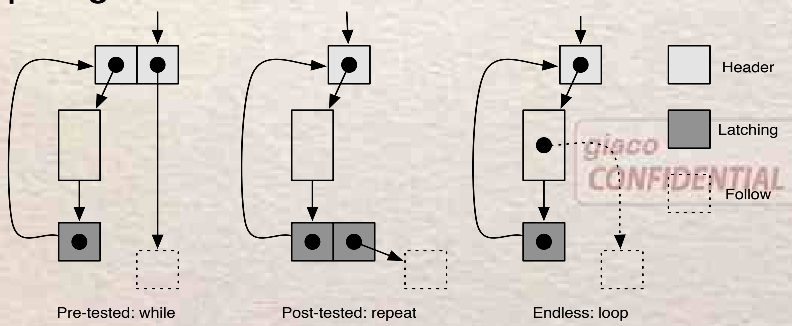
$$i: \quad \texttt{call} \quad addr \quad \Rightarrow \quad i: \quad \texttt{call}\ name$$

DECOMPILATION: RESTRUCTURINGLOOPS(G)

S. Muchnick. Advanced compiler design and implementation, 1997 :

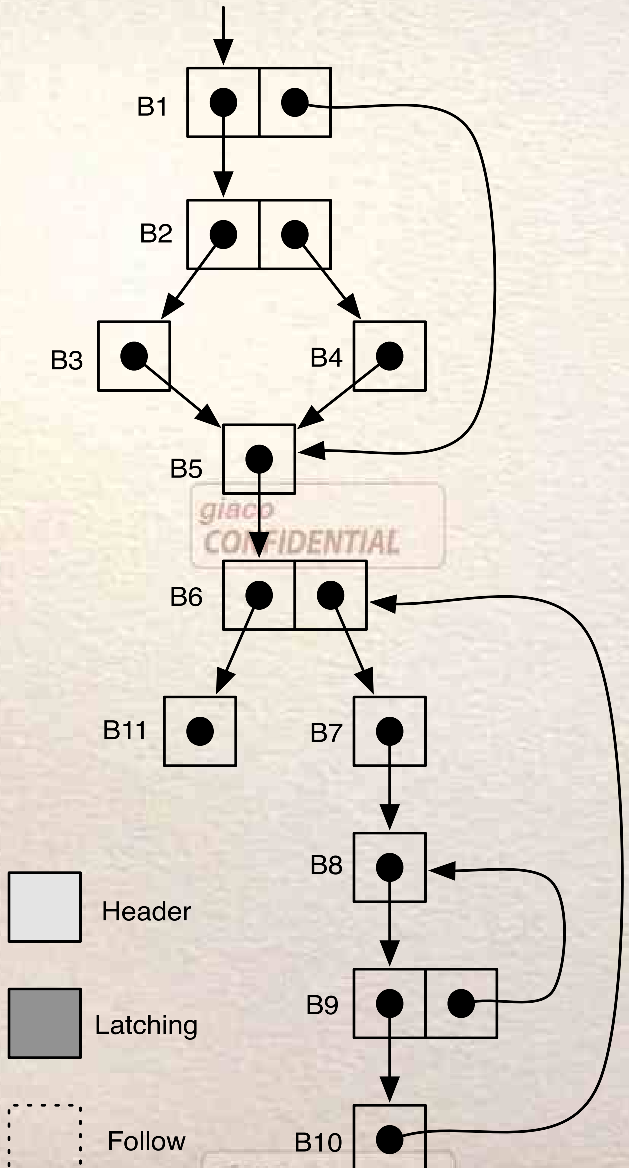
- $I(h)$ is an interval graph of G if it is the maximal single-entry subgraph of G having h as the only entry node and where all closed paths include h.

- Input CFG G:
  1. Derive the Interval Graphs $\{I_1(h_1), \ldots, I_m(h_m)\}$ of G;
  2. Determine loop-type: pre-tested, post-tested, endless
     - ✔ `forall` $I(h)$ `find the latching node in` $I(h)$;
     - ✔ `match the loop against`:

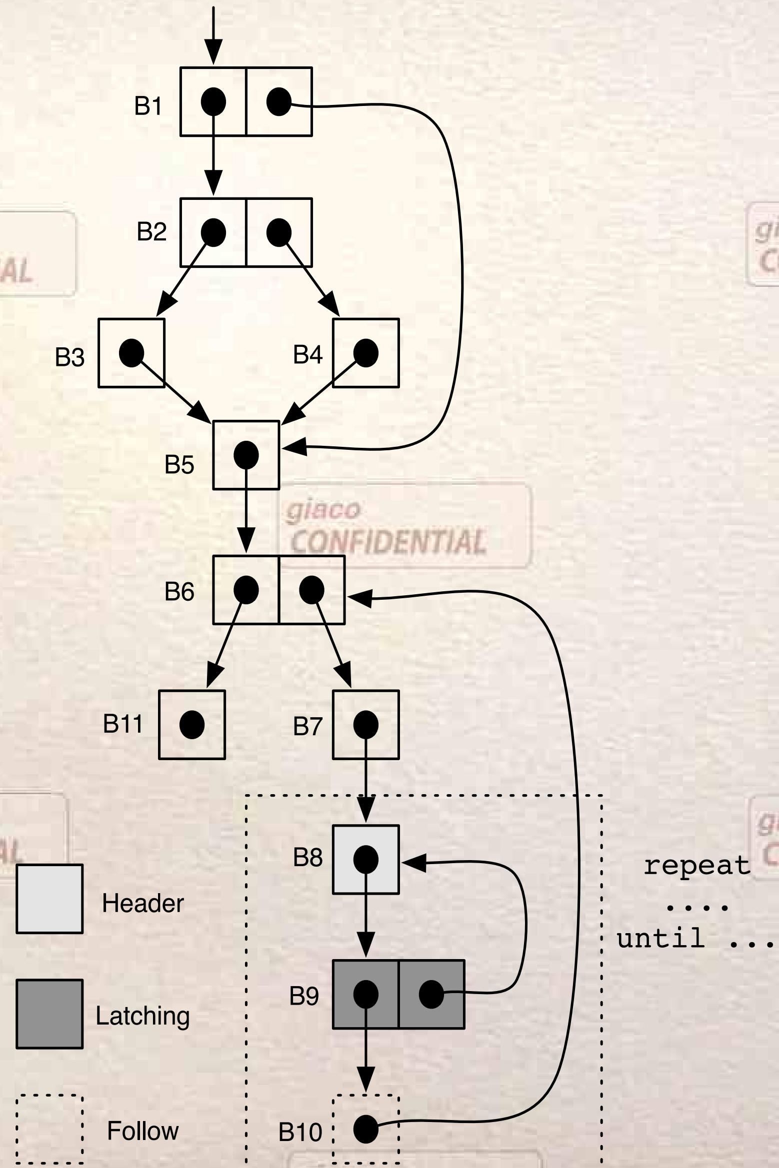


     - ✔ `mark` h `with loop type`
  3. Repeat from 2 until all intervals in G are collapsed into one (loop) node

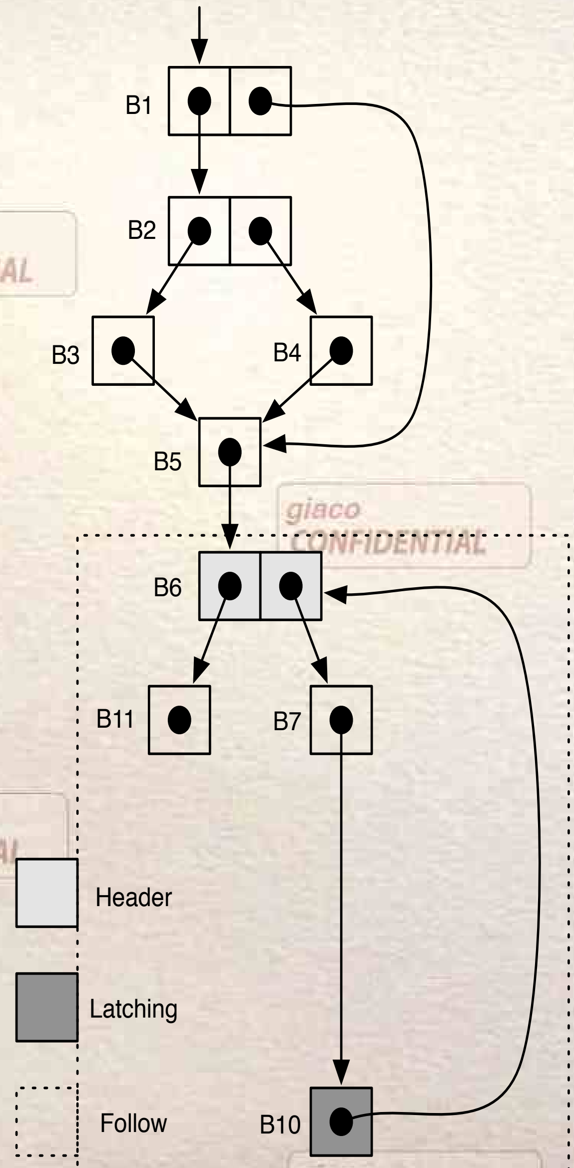
DECOMPILATION: DISCOVERING LOOPS



DECOMPILATION: DISCOVERING LOOPS



DECOMPILATION: DISCOVERING LOOPS




```
while ... {
  repeat
   ....
  until ...
    }
```

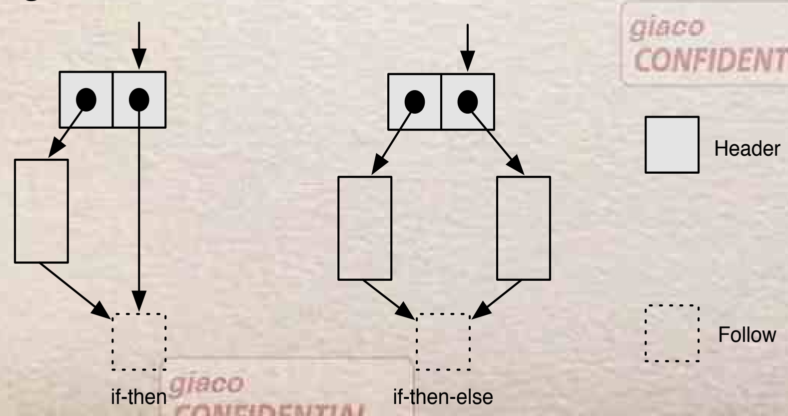
Decompilation: RestructuringIfs(G)

Input CFG G:

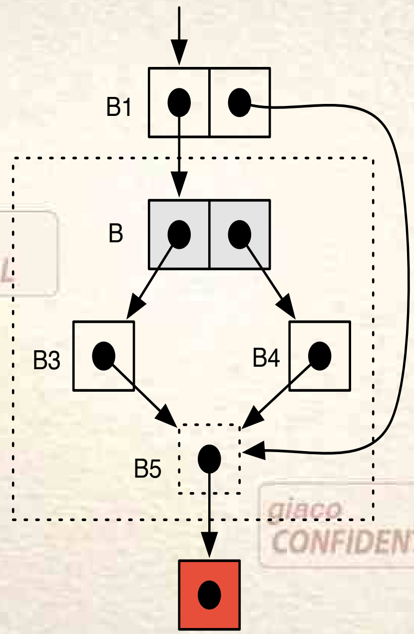
1. Number the nodes of G in reverse postorder;
2. Determine unresolved nodes:

```
unresolved := ∅
forall node m by descending reverse postorder do
   if m is 2-way and not loop header then
   if ∃n :  n = max { i | idom(i) = m ∧ |inEdge(i)| ≥ 2 }
      then follow(m) := n
      foreach x ∈unresolved do
        follow(x) := n; unresolved:=unresolved - {x}
   else unresolved := unresolved ∪{m}
```

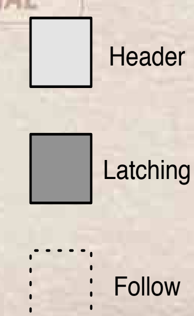
3. Match the if type against:



DECOMPILATION: DISCOVERING IFS

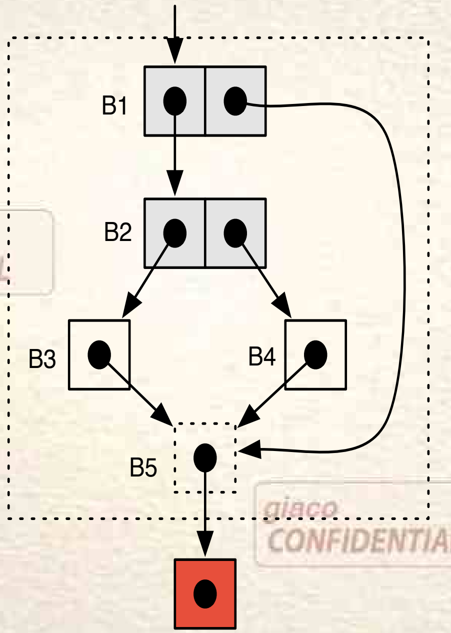



```
if (...) {
  ....
 }
else {
  ....
}
```

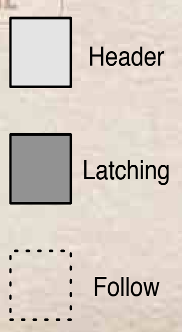



```
while ... {
  repeat
   ....
 until ...
    }
```

DECOMPILATION: DISCOVERING IFS




```
if (...) {
  if (...) {
    ....
  }
  else {
   ....
  }
}
```




```
while ... {
   repeat
    ....
  until ...
     }
```