A lean retargetable C compiler

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Optimize *our* time

- Minimize source code
- Compile fast
- Emit satisfactory code
- One literate program emits two outputs:
  - A Retargetable C Compiler: Design and Implementation. Addison Wesley.
  - http://www.cs.princeton.edu/software/lcc/

One source

The string table is an array of 1,024 hash buckets:

```
<<data>>=
static struct string {
        char *str;
        int len;
        struct string *link;
} *buckets[1024];
@ Each bucket heads a list of strings that share
 a hash value.
```

Sizes

- 12K lines target-independent
- Plus1K lburg
- Plus ~700 lines per target:
  - tree grammar
  - code for proc entry/exit, data ...
- 400KB code segment includes 3 real targets + 2 for debugging.

Compile/execution times

- Compiles itself in half the time of gcc
- Emitted code generally within 20% of gcc's

Code generation interface: Dags

- Shared data structures
- 36 base opcodes:
  - ADD INDIR JUMP …
- 9 base types:
  - I D C …
- but only 108 combos:
  - ADDI INDIRC ...

Interface functions

- begin/end module, function, block
- select/emit code
- define symbol
- emit initialized data
- change segment

Interface record

```
typedef struct interface {
   unsigned little_endian:1;
   void *(defsymbol)(Symbol);
   ...
}
```

```
lcc -Wf-target=x86-linux foo.c
```

Code generation specs

- Tree grammars match IR and emit asm code
- Sample rules:

```
reg: ADDI(reg,con)
    "addu $%c,$%0,%1\n"  1
addr: ADDI(reg,con) "%1($%0)"  0
```

- Specs: ~200 rules
- Hard-coded, bottom-up, optimal tree matchers, ~2000 lines

Twists

- Link-time CG: Fernandez
- Run-time CG: Poletto, Engler, Kaashoek
- Emit Java, even C: Fraser, Huelsbergen
- Debuggers: Hanson, Ramsey, Raghavachari
- Optimize battery life: Tiwari

More twists

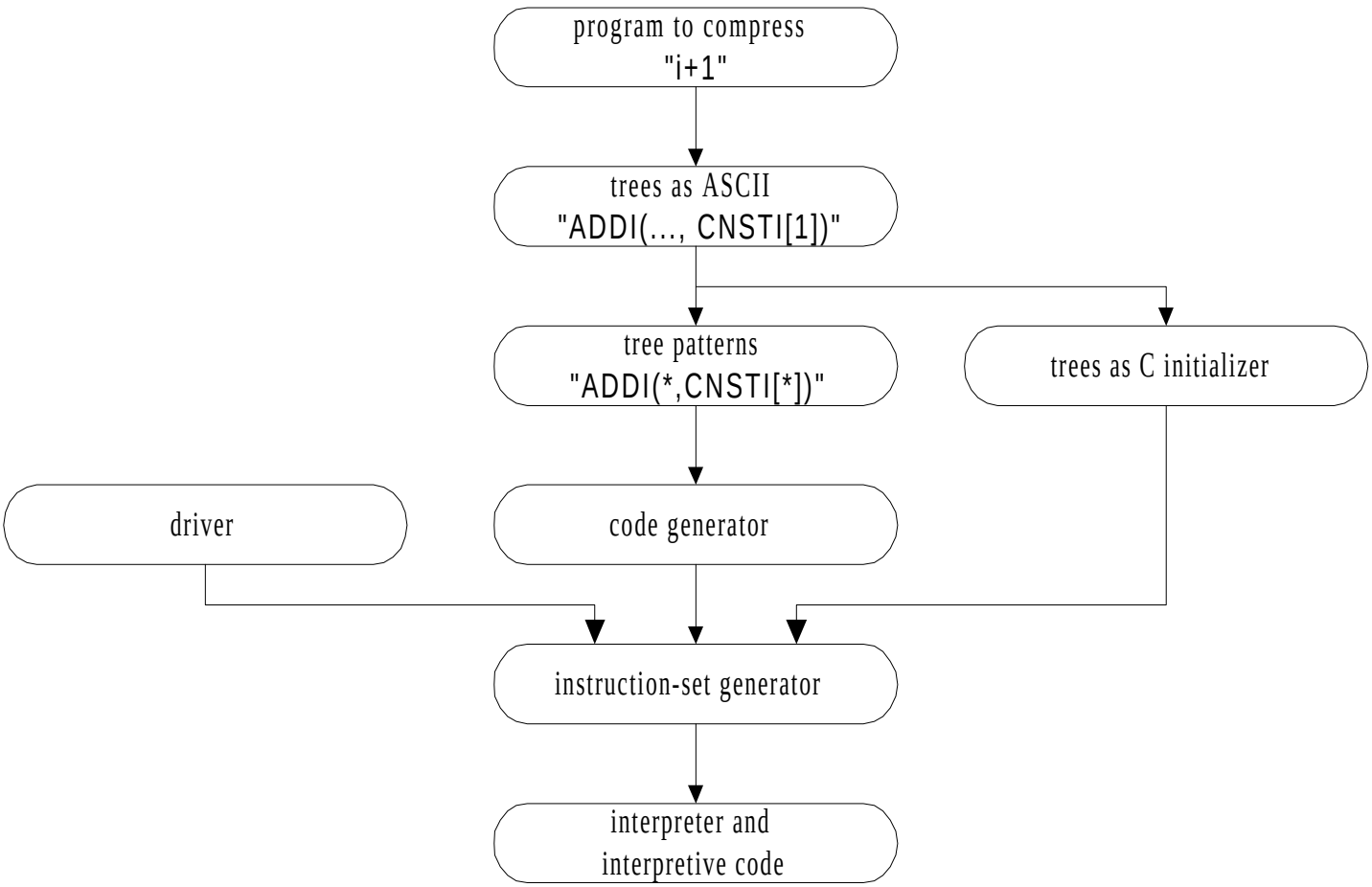
- Compress code: Fraser, Proebsting
- Program directors: Sosic
- Browse code: Fraser, Pike
- Audit trees: Proebsting

Code compression

Proebsting and Fraser

- Accept a C program
- Emit:
  - a custom interpreter
  - postfix bytecodes
- Suits ROM, Java, optimizing linkers?

Organization



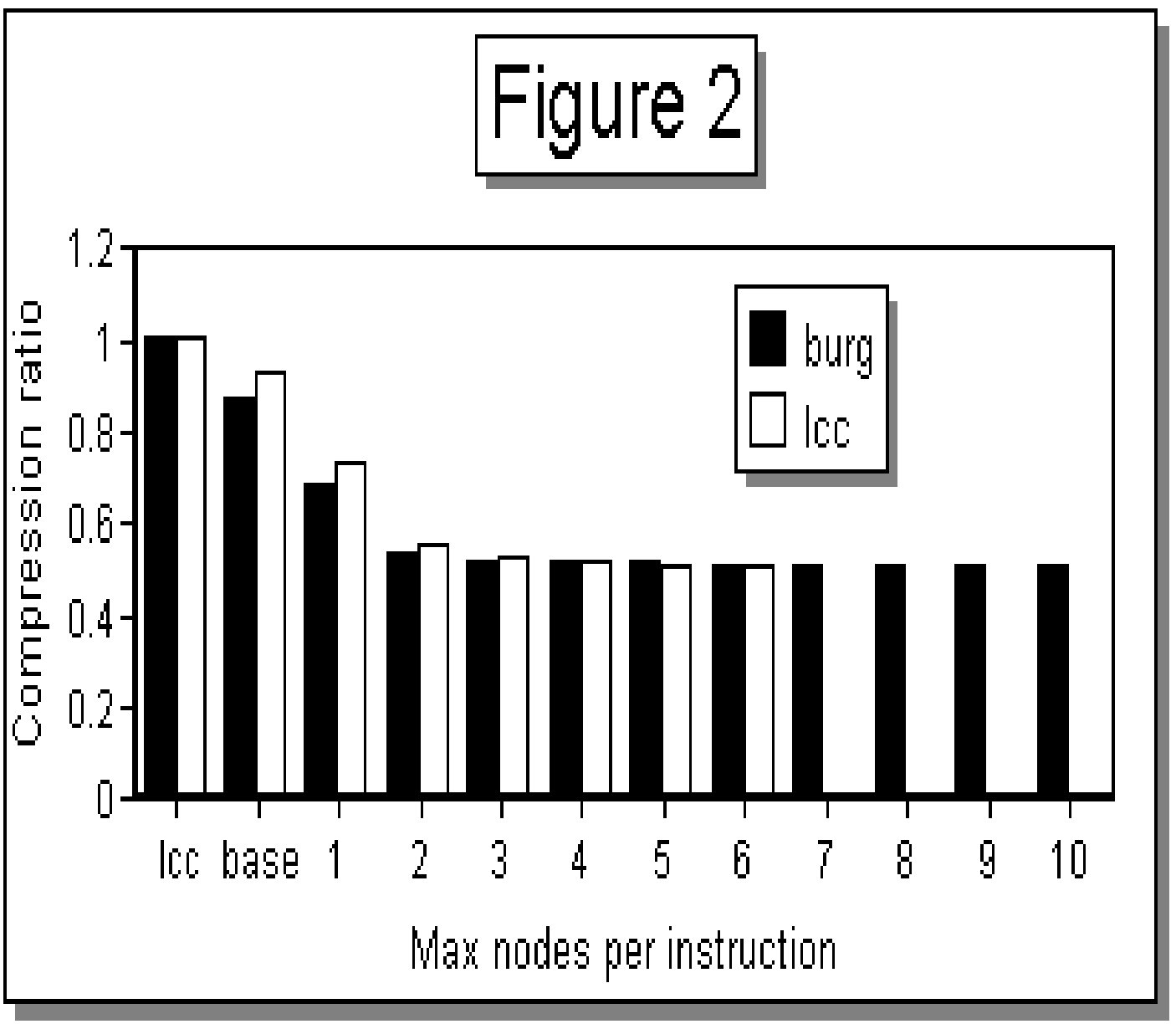
Assigning opcodes

- Enumerate all trees:
  - ADDI(INDIRI(ADDRGP[i]),CNSTI[1])
- Patternize, up to some limit:
  - ADDI(*,CNSTI[*])
  - ADDI(*,CNSTI[1]) ...
- Generate a *huge* code generator

… continues

- Assign codes to all IR ops used by the program at hand
- With leftover codes, pick pattern that saves the most, then loop

Results



Run-time CG

Poletto, Engler, Kaashoek

- Construct code to sum n int args:

```
void cspec ConstructSum(int n) {
    int k, cspec c = `0;
    for (k = 0; k < n; k++) {
        int vspec v = (int vspec)
                param(k, TC_I);
        c = `(@c + @v);
    }
    return `{return @c};
}
```

Translate C to Java

Huelsbergen, Fraser

```
class FromLCC {
    public static int _main() {
        int pc = 0;
        M.sp -= 16;
        while(true) switch (pc) {
        ...
i=0     case 3:  M.putint((M.sp+4), 0);
        case 6:  M.putint(((M.getint(
rows[i]=1                   (M.sp+4))<<2)+_rows), 1);
        case 7:  M.putint((M.sp+4),
i++                         (M.getint((M.sp+4))+1));
                 if (M.getint((M.sp+4)) < 8) {
if(i<8)goto case 6          pc=6; continue; }; ...
    }
```

Program directors

Sosic

- Mix interpretive, compiled code
- Interpreter sends a (filtered) stream of events from the *executor* to the *director*
  - time, pc, result, ...
- Director watches and ...
  - animates calls,
  - watches for corrupt state, ...

Audit trees

Proebsting

- Some trees make no sense:
  - INDIRC(ADDF(*,*))
- One “back end” emits only Yes or No but matches with a grammar that specifies the valid trees. *We* run it.

Big mistakes

- Need ASTs
- Need flow graphs
- “Economized” on long and void* metrics for too long
- Need interface pickle (now plural)
- Need better modularization:
  - Half the patches create a new error. See Dave’s coming book.

Smaller mistakes

- A graph-coloring register allocator
- Instruction scheduling
- Peephole optimization

What we like

- Simple and thus good infrastructure
- Fast
- Portable
- Complete
- Validated and kept that way
- We’d miss flexibility and fast compiles more than global opts