Early Experience with ASDL in lcc

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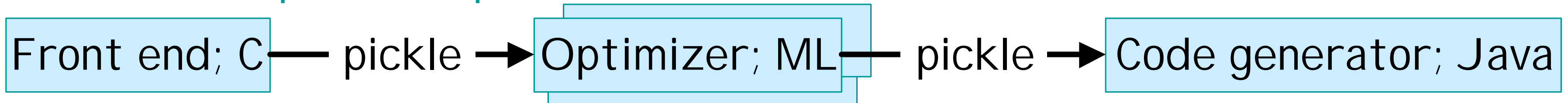
Roadmap

- About: Abstract Syntax Description Language (ASDL) [3 slides]
- About: The lcc code-generation interface [3]
- Using ASDL to divide lcc into N separate programs [2]
- The details … ZZZ… [11]
- Good: finds bugs, constrains algorithms, define data structures, … [1]
- Bad: redundant data structures, constrains algorithms, graphs, … [2]
- What happens next? [1]

- Executive Summary: ASDL works in a real compiler

Abstract Syntax Description Language (ASDL)

- What: A language for specifying tree intermediate representations – tree data structures, e.g., ASTs
- Why: Promote interoperability of compiler parts written in different languages
- How: Given an ASDL specification, <u>generate</u>
  - Data structure declarations in C, C++, Java, ML, or Haskell
  - Code to read/write data structures as language- and machine-independent "pickles"



- Cynic's view: Uses RPC technologies – IDLs, stub generation – to build modular compilers

Example: IR for Assignments + Print Statements

- In IR.asdl:

```
stm    = SEQ(stm, stm)
       | ASGN(identifier, exp)
       | PRINT(exp*)
exp    = OP(binop, exp, exp)
       | ID(identifier)
       | CON(int)
binop = ADD | SUB | MUL | DIV
```


- Given IR.asdl, generator emits for C (ditto for Java, …)
  - IR.h declarations for types, functions
  - IR.c code for constructors, readers, writers
- "Producers" use IR.[ch] to build and write IR pickles
- "Consumers" use IR.[ch] to read IR pickles

Example: Generated Code

- IR.h holds type declarations, prototypes:

```
typedef struct exp_s *exp_ty;
struct exp_s {
  enum {OP_enum, ID_enum, CON_enum} kind;
  union {
   struct OP_s { binop_ty binop1; exp_ty exp1,exp2;} OP;
   struct ID_s { identifier_ty identifier1;} ID;
   struct CON_s { int_ty int1;} CON;
  } v;
};
```

- IR.c holds constructors, etc., e.g., to construct OPs:

```
exp_ty OP(binop_ty binop1, exp_ty exp1, exp_ty exp2) {
  IR_exp_ty ret = alloc(sizeof(*ret));
  ret->kind = OP_enum;
  ret->v.OP.binop1 = binop1;
  ret->v.OP.exp1 = exp1; ret->v.OP.exp2 = exp2;
  return ret;
}
```

lcc 4.x Code-Generation Interface

- Shared data structures: nodes, symbols, types, metrics
- 33 generic intermediate representation (IR) operators

```
CNST  ARG   ASGN  INDIR CVF   CVI   CVP   CVU
NEG   CALL  RET   ADDRG ADDRF ADDRL ADD   SUB
LSH   MOD   RSH   BAND  BCOM  BOR   BXOR  DIV
MUL   EQ    GE    GT    LE    LT    NE    JUMP  LABEL
```

- 6 type suffixes: F I U P B V
- Up to 9 sizes: 5 integer, 3 floating, 1 pointer
- Semantics + size overlap reduce operator repertoire
  - ~ 130 type/size-specific operators for 32-bit targets

```
CVIF4 CVIF8
CVII1 CVII2 CVII4
CVIU1 CVIU2 CVIU4
...
MULF4 MULF8 MULI4 MULU4
```

18 Code-Generation Functions

- Initialize/finalize a back end
  - progbeg, progend
- Define/initialize symbols
  - address, local, defsymbol, global, import, export
- Initialize/finalize scopes
  - blockbeg, blockend
- Generate/emit code
  - gen, emit, function
- Generate initialized data
  - defconst, defstring, defaddress, space, segment
- Instruction selection specified by short machine specs.
  - IBURG-style tree pattern matcher
  - Optimal local code

Interface Records & Cross Compilation

- Interface records hold target-specific interface data

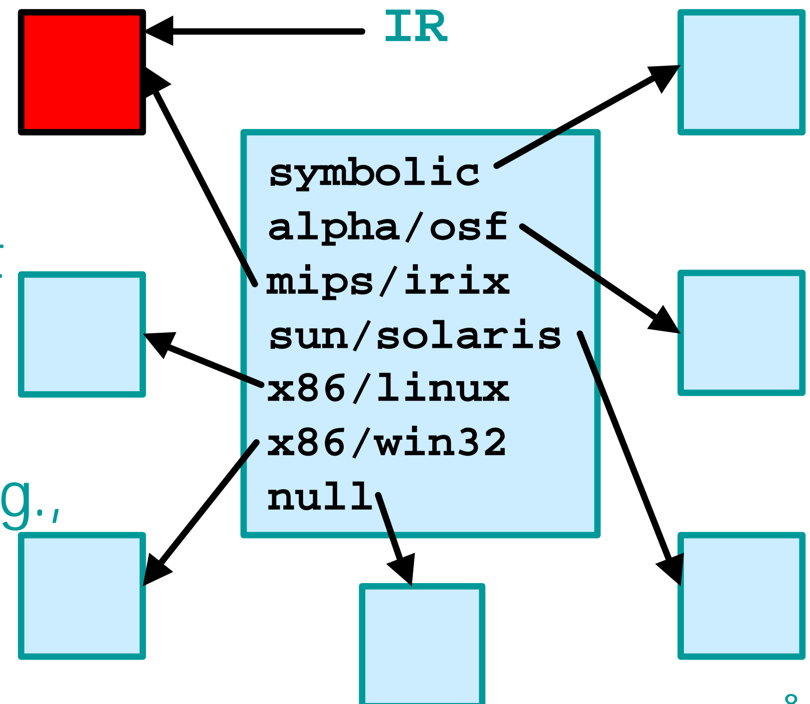
```
typedef struct interface {
  Metrics charmetric; … structmetric;
  unsigned little_endian:1; … unsigned unsigned_char:1;
  void (*address)(Symbol p, Symbol q, long n);
  void (*blockbeg)(Env *e);
  …
  void (*space)(int n);
  Xinterface x;
} Interface;
```

- Compile-time option *binds* front end to an interface record:

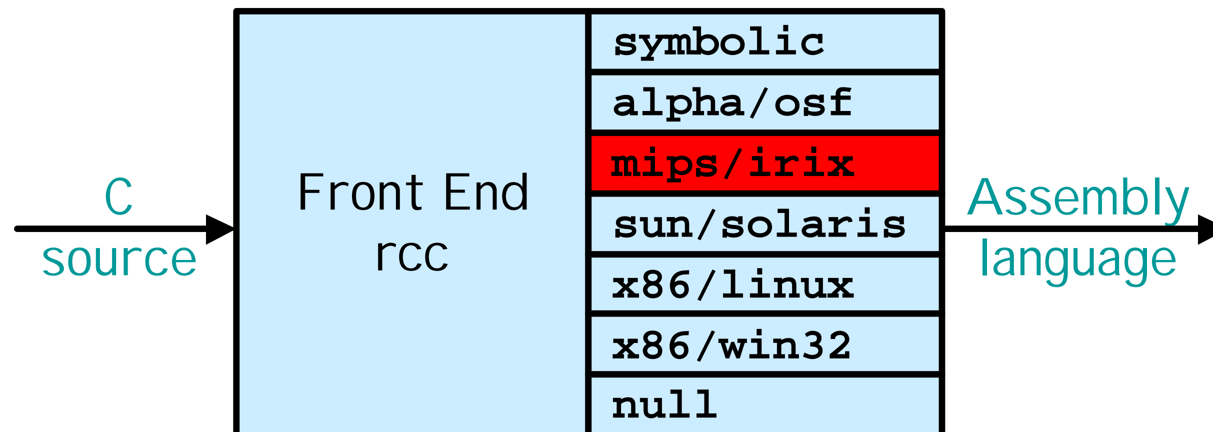
  % lcc -Wf-target=mips/irix -S wf1.c

- Front end uses indirect calls, e.g.,

```
(*IR->defsymbol)(p);
```



lcc is a Monolithic Compiler — By Design

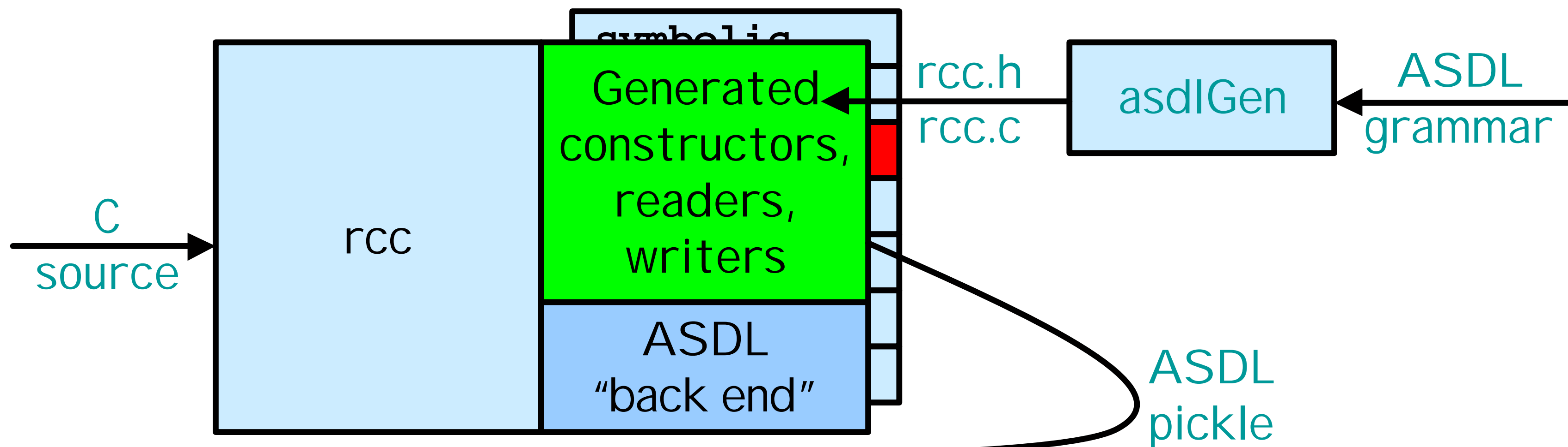


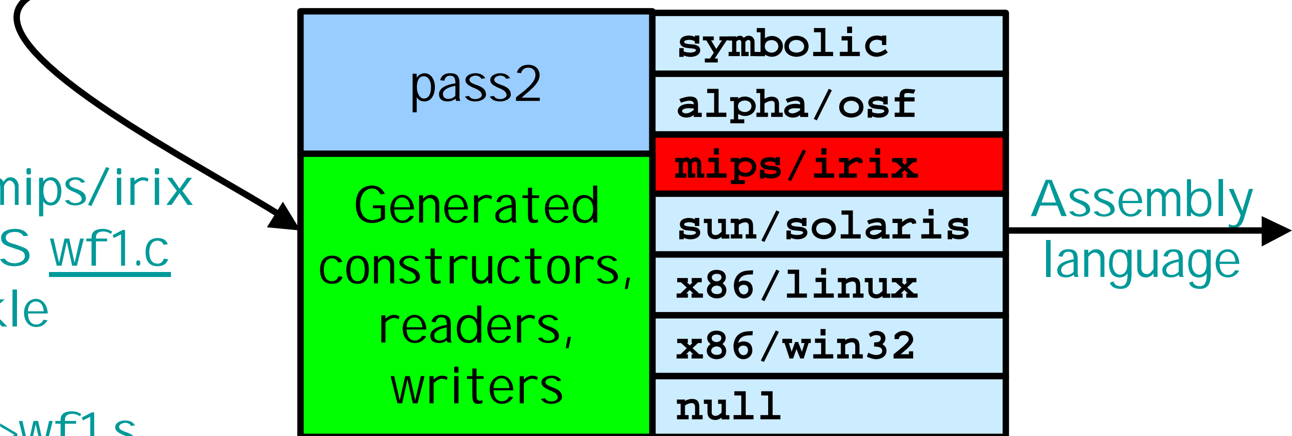
- Small footprint (x86 under NT 4.0):

873 KB	front end + all back ends
21	common back end support, e.g., register allocator
55	MIPS back end
...	
89	X86/Linux back end

- Interface has upcalls, so assumes one address space

Use ASDL to Divide lcc





% lcc -Wf-target=mips/irix
-Wf-asdl -S wf1.c
% mv wf1.s wf1.pickle
...
% pass2 wf1.pickle >wf1.s
% 2html wf1.pickle >wf1.html

lcc ASDL Grammar (~70 lines)

- Encodes interface data structures + calls
  - Pickles depend on the target, e.g., type sizes, alignments
  - Pickles depend on platform, e.g., system-dependent header files
- Pickles include excess baggage necessary for pass2

```
module rcc {
  program = (int nuids,int nlabels,item* items,
            interface* interfaces,int argc,string *argv)
  item    = Symbol(symbol symbol)
          | Type(type type)    attributes(int uid)
  symbol          = ¼     -- symbol-table entries
  type            = ¼     -- type representation
  interface       = ¼     -- interface function calls
  node            = ¼     -- IR trees
}
```

- Use integers to represent unique items, e.g., symbols
  - I.e., To encode DAGs

Symbols

```
symbol = (identifier id,int type,int scope,
                           int sclass,int ref,int flags)
   struct node {
     int count;
     …
   };
   main() { struct node *root; … }

(id = root, type = 10, scope = LOCAL, sclass = AUTO,
   ref = 120000, flags = addressed)
```

- Built-in types: **`identifier`**, **`int`**
- Identifiers are unique
- Types identified by unique integers (uids)

Types

```
field      = (identifier id,int type,int offset,
                    int bitsize,int lsb)
enum       = (identifier id,int value)
type       = INT
           | UNSIGNED
           | FLOAT
           | VOID
           | POINTER(int type)
           | ENUM(identifier tag,enum* ids)
           | STRUCT(identifier tag,field* fields)
           | UNION(identifier tag,field* fields)
           | ARRAY(int type)
           | FUNCTION(int type,int* formals)
           | CONST(int type)
           | VOLATILE(int type)
           attributes(int size,int align)
```

- ASTs represent types

Example: Representing struct node

```
struct node {
  int count;
  struct node *left;
  struct node *right;
  char *word;
};
11: STRUCT( size = 16, align = 4, fields = [
             id    type  offset  bitsize  lsb
            (count, 12,     0,       0,     0),
            (left,  10,     4,       0,     0),
            (right, 10,     8,       0,     0),
            (word,  13,    12,       0,     0)] )
12: INT(     size =  4, align = 4)
10: POINTER(size =  4, align = 4, type = 11)
13: POINTER(size =  4, align = 4, type =  8)
 8: INT(     size =  1, align = 1)
```

Associating uids with Types and Symbols

```
program    = (int nuids,int nlabels,item* items,
              interface* interfaces,int argc,string *argv)
   item    = Symbol(symbol symbol)
           | Type(type type)    attributes(int uid)

(nuids = 97, nlabels = 55, items = [
  Type(  uid =  8, INT(size =  1, align = 1)),
  Type(  uid = 12, INT(size =  4, align = 4)),
  …
  Symbol(uid = 23, (id = printf, type = 29, … )),
  …
  Type(  uid = 94, ARRAY(size = 32000, …, type = 11)),
  Symbol(uid =  1, (id = words, type = 94, … )) ]
interfaces = [ … ], argc = 5,
argv = [ "x86\win32\rcc.exe", "-target=x86/win32",
  "-asdl", … ]
)
```

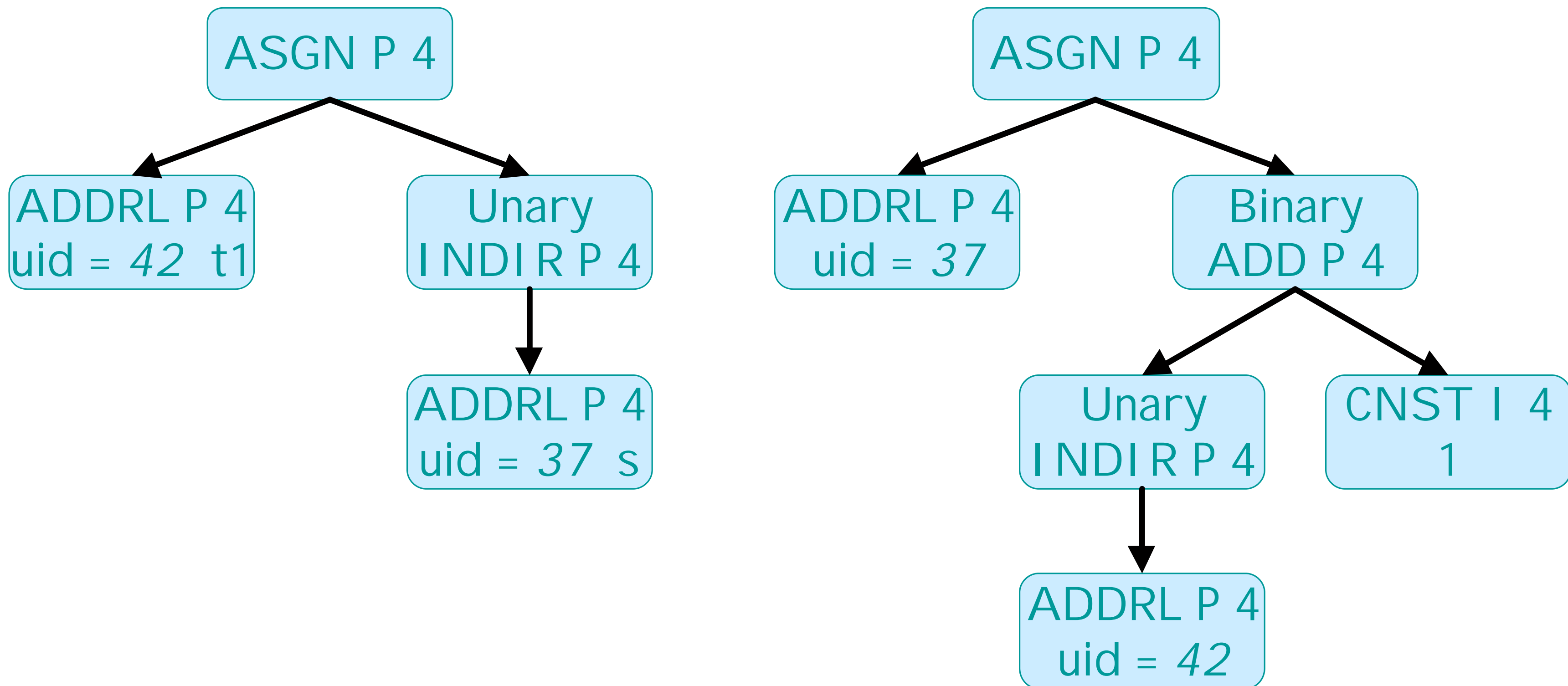
- See wf1.html

IR Trees

```
node = CNST(int value)
     | CNSTF(real value)
     | ARG(node left,int len,int align)
     | ASGN(node left,node right,int len,int align)
     | CVT(int op,node left,int fromsize)
     | CALL(node left,int type)
     | CALLB(node left,node right,int type)
     | RET
     | ADDRG(int uid)
     | ADDRL(int uid)
     | ADDRF(int uid)
     | Unary(int op,node left)
     | Binary(int op,node left,node right)
     | Compare(int op,node left,node right,int label)
     | LABEL(int label)
     | BRANCH(int label)
     | CSE(int uid,node node)
    attributes(int suffix,int size)
```

Example: char *s; int c; *s++ = c

- `t1 = s; s = t1 + 1; *t1 = c;`

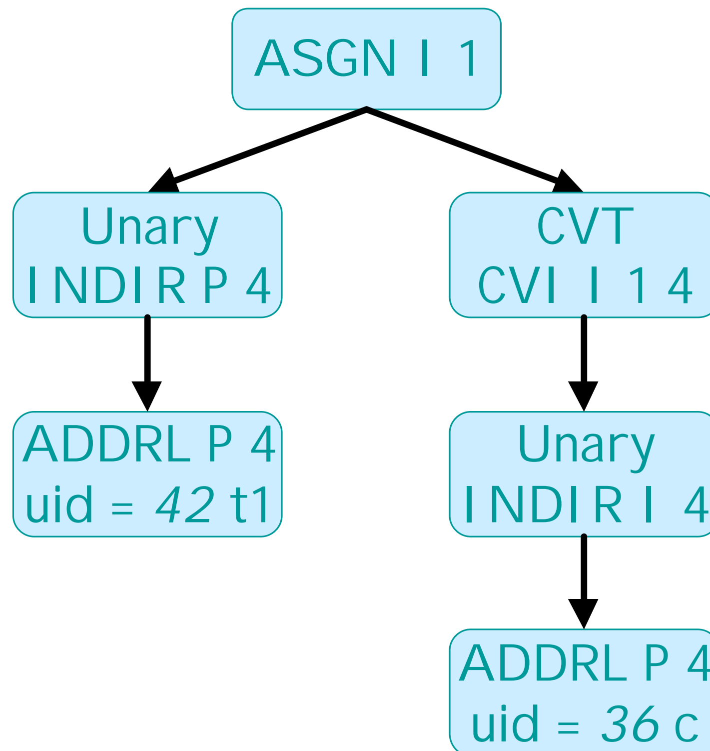


- Nodes are written in prefix

```
ASGN P 4 ADDRL P 4 42 Unary INDIR P 4 ADDRL P 4 37
```

Example: char *s; int c; *s++ = c

- `t1 = s; s = t1 + 1; *t1 = c;`



Interface Function Calls

```
interface   = Export(int p)
            | Import(int p)
            | Global(int p,int seg)
            | Local(int uid,symbol p)
            | Address(int uid,symbol q,int p,int n)
            | Segment(int seg)
            | Defaddress(int p)
            | Deflabel(int label)
            | Defconst(int suffix,int size,int value)
            | Defconstf(int size,real value)
            | Defstring(string s)
            | Space(int n)
            | Function(int f,int* caller,int* callee,
                   int ncalls,interface* codelist)
            | Blockbeg
            | Blockend
            | Forest(node* nodes)
```

Interface Encodes Code-Generation Calls

```
(nuids = 97, nlabels = 55, items = […],
  interfaces = [
    Export(p = 4 main),
    Segment(seg = CODE),
    Function(f = 4 main, …),
    …
    Local(uid = 27, symbol = (id = s, …)),
    Local(uid = 28, symbol = (id = s, …)),
    Function(f = 22 err, caller = [ 27 ], callee = [ 28 ],
           ncalls = 2, codelist = [
                 Blockbeg(),
                 Forest(nodes = …),
                 Forest(nodes = …),
                 Blockend(),
                 Forest(nodes = …)]),
    …
    Defstring("? %s\n") ]
  argc = 5, argv = […]
)
```

```
err(s) char *s; {
        printf("? %s\n", s);
        exit(1);
}
```

Statistics

- Programmer-written code:

70	lines	ASDL specification
358		ASDL "back end"
681		pass2.c
559		2html.c

- Generated code (from ASDL spec.):

313	lines	rcc.h
1870		rcc.c

- Executables:

853	KB	rcc
846		pass2
202		2html

- Pickles:

4059	bytes	wf1.pickle
2148		wf1.o (x86 under Linux)

Good Things

- Helps find bugs

```
f(void) { extern int x; … }
int x;
```

  - Bug: *two* symbol-table entries with identical contents

```
static int x;
f(void) { extern int x; … }
```

  - Bug: two symbol-table entries, and inner x appears to be static when declared, extern when used (!)

- Constrains algorithms/binding times

```
f(x, y) char x; int y; { … }
```

is compiled as

```
f(? int x′, ? int y′) { ? char x = x′; ? int y = y′; …}
```

  - Back end sets ?, front end emits only necessary assignments
  - pass2 must emit assignments

Bad Things

- Redundant data structures
  - Everything written to a pickle has at least two representations

	types	*symbols*	*nodes*	*calls*	*other*
lcc	`type` `field`	`symbol` `table`	`node` `tree`	`code`	
ASDL	*`type`* *`field`* *`enum`*	*`symbol`*	*`node`*	*`interface`*	*`item`* *`program`* *`sequence`*

  - Plus constructors, allocators, etc. – use ASDL from the outset
- Constrains algorithms/binding times

```
a = b*c + b*d
```

  - Load **`b`** into a temp? Not if **`b`** is in a register, or temp isn't
  - Front end inserts possibly useless temps; pass2 eliminates them
- Little help in dealing with graphs
  - Mappings of integers to data structures, e.g., item, are common

Ambiguity

- Bad: ASDL grammar admits invalid trees, code lists

```
program     = (int nuids,int nlabels,item* items,
               interface* interfaces,int argc,string *argv)
node        = …
            | CVT(int op,node left,int fromsize)
            …
            | Binary(int op,node left,node right)
interface   = …
            | Function(int f,int* caller,int* callee,
                   int ncalls,interface* codelist)
```

- Good: Ambiguity permits compact grammars
- Hindsight: Ambiguity admits bugs
  - Debugging binary pickles at runtime is tedious
  - Non-ambiguous grammars help catch errors at compile-time, and are better documentation

What Happens Next?

- Add more information, e.g., for optimization
  - Flow graph, live ranges
  - Debugging information, e.g., visibility information, source coordinates
- Investigate XML – isomorphic to ASDL
  - Leverage widely available XML tools?
  - XML Document Type Declaration (DTD) Û ASDL
  - Use XML's ID/IDREF attributes to handle graphs?
- Design new code-generation interfaces
  - Target-independent; ANDF?
  - Family of code-generation interfaces?
- Use ASDL elsewhere
  - Data structure definitions
  - Interface specifications