CSE401: Lexing

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Where are we?

1. Define the tokens for the language using regular expressions
   - Natural representation for tokens
   - But difficult to produce a scanner from REs
2. Convert the regular expressions into non-deterministic finite state automata (NFA)
   - Straightforward conversion
   - Can produce a scanner from NFA, but an inefficient one
3. Convert the NFA into deterministic finite state automata (DFA)
   - Straightforward conversion
4. Convert the DFA into an efficient scanner implementation

Why convert to DFAs?

- Because
  - they are equivalent in power to NFAs
  - they are deterministic, which makes them a terrific basis for an efficient implementation of a scanner

NFA => DFA

- Basic problem
  - NFA can choose among alternative paths
    - either ε transitions or
    - multiple transitions from a state with the same label
  - But a DFA cannot have this kind of choice
- Solution: subset construction
  - In the newly constructed DFA, each state represents a *set* of states in the NFA, all of which the NFA might be in during its traversal

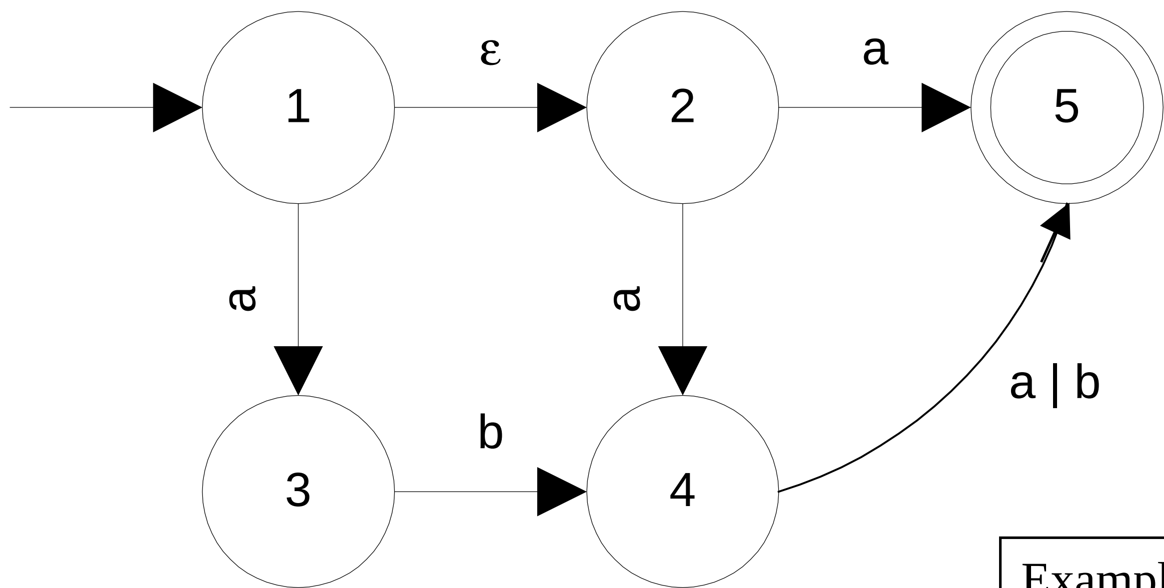
Subset construction algorithm

initial step

- Create start state of new DFA
  - Label it with the set of NFA states that can be reached by ε transitions
    - That is, without consuming any input
    - Think of it as all possible start states in the NFA, since there could be more than one given ε transitions
- Then process this new start state
  - Details in a couple of slides

In groups (and stay there!)

< 1 minute: start state of the new DFA?



Example from
Crafting a Compiler,
Fischer & LeBlanc

Subset construction algorithm

processing a state

- To process a state S in the new DFA with label $\{s_1,\ldots,s_n\}$
- For each symbol x in the alphabet
  - Compute the set T of NFA states reached from any of the NFA states $s_1,\ldots,s_n$ by an x transition followed by any number of ε transitions
  - If T is not empty
    - If there is already a DFA state with T as a label, add a transition labeled x from S to T
    - Otherwise create a new DFA state labeled T, add a transition labeled x from S to T, and then process T

Same groups:

apply the algorithm

Subset construction algorithm

defining final states

- After the algorithm terminates
- Mark every DFA state as final if *any* of the NFA states in its label is final

Same groups:

mark final states

Subset construction: notes

- It is provable that this works and produces an equivalent DFA
- This activity can be automated
- Question: What can be said about the number of states in the DFA relative to the NFA?
  - In theory? In practice?

Minimizing DFAs

- There is also an algorithm for minimizing the number of states in a DFA
- Given an arbitrary DFA, one can find a unique DFA with a minimum number of states that is equivalent to the original DFA
  - Except for a renaming of the states
  - Essentially, try to merge states

Constructing scanners from DFAs

- Use a table-driven scanner
- Write disciplined procedures that encode the DFA
- We’ll talk about both (the first briefly)
- The second approach is used in the PL/0 compiler
  - Because it’s generally easier to handle a few practical issues (and it may be faster)

Table-driven scanner

- Represent the DFA as an adjacency matrix
  - One row per state
  - One column per character in the alphabet
  - Entry is state to transition to
- Mechanically walk the input, taking appropriate transitions
  - Rules for termination remain unchanged

	a	b
{1,2}	{3,4,5}	
{3,4,5}	{5}	{4,5}
{4,5}	{5}	{5}
{5}		

Approach 2: procedural

- Define a procedure for each state in the DFA
- Use conditionals to check the input character and then make the appropriate transition
- A transition is a call to the procedure for the next state

```
procedure {3,4,5} begin
  if nextChar() == 'a'
    call {5}
  elsif nextChar() == 'b'
    call {4,5}
  else
    reject("no transition
            out of this
            state")
end
```

The heart of the PL/0 scanner

it's not quite as clean (but it's not bad!)

```
Token ::= Id |
          Integer |
          Keyword |
          Operator |
          Punct
```

- Where's the DFA?
- How come five kinds of tokens and only three branches?

```
if (isalpha(CurrentCh)) {
   T = GetIdent()
} else if (isdigit(CurrentCh)) {
   T = GetInt()
} else {
   T = GetPunct();
}
```

PL/0's `GetIdent` method

In groups, answer these questions

- Is PL/0 case-sensitive?
- What does `SearchReserved` return?

```
Token* Scanner::GetIdent() {
  char ident[MaxIdLength+1];
  int LengthOfId = 0;
  while (isalnum(CurrentCh)) {
    ident[LengthOfId] =
         tolower(CurrentCh);
    LengthOfId ++;
    GetCh();
  }
  ident[LengthOfId] = '\0';
  return SearchReserved(ident);
}
```

PL/0's `GetInt` method

```
Token* Scanner::GetInt() {
  int integer = 0;
  while (isdigit(CurrentCh)) {
    integer = 10 * integer + (CurrentCh - '0');
    GetCh();
  }
  return new IntegerToken(integer);
}
```

PL/0's GetPunct method

```
Token* Scanner::GetPunct() {
  Token* T;
  switch (CurrentCh) {
    case ':':
      GetCh();
      if (CondReadCh('=')) {
        T = new Token(GETS);
      } else {
        T = new Token(COLON);
      }
      break;
```

```
case '<':
  GetCh();
  if (CondReadCh('=')) {
    T = new Token(LEQ);
  } else if (CondReadCh('>')){
    T = new Token(NEQ);
  } else {
    T = new Token(LSS);
  }
  break;
  …
```

A few other notes about the scanner

- There is a `Scanner` class
  - There is only one instance of this class
  - This is an example of the *Singleton* design pattern
- The high-level structure we showed has the scanner scan before the parser parses
  - Study the compiler to figure out what really happens
- Make sure (for this and all other phases) to read the interface (the `.h` file) very, very carefully

Language design issues (lexical)

- Most languages are now free-form
  - Layout doesn't matter
  - Use whitespace to separate tokens, if needed
  - Alternatives include
    - Fortran, Algol68: whitespace is ignored
    - Haskell: use layout to imply grouping
- Most languages now have reserved words
  - Cannot be used as identifiers
  - Alternative: PL/0 has keywords that are treated specially only in certain contexts, but may be used as identifiers, too

Objectives: next lectures

- Understand the theory and practice of parsing
- Describe the underlying language theory of parsing (CFGs, etc.)
- Understand and be able to perform top-down parsing
- Understand bottom-up parsing