Examination in Compilers, EDAN65

Department of Computer Science, Lund University

2018–10–30, 14.00-19.00

Note! **Your exam will be marked only if you have completed all six programming lab assignments in advance.**

Start each solution (1, 2, 3, 4) on a separate sheet of paper. Write your *personal identifier*[1] on every sheet of paper. Write clearly and legibly. Try to find clear, readable solutions with meaningful names. Unnecessary complexity will result in point reduction.

The following documents may be used during the exam:

- *Reference manual for JastAdd2*
- *x86 Cheat Sheet*

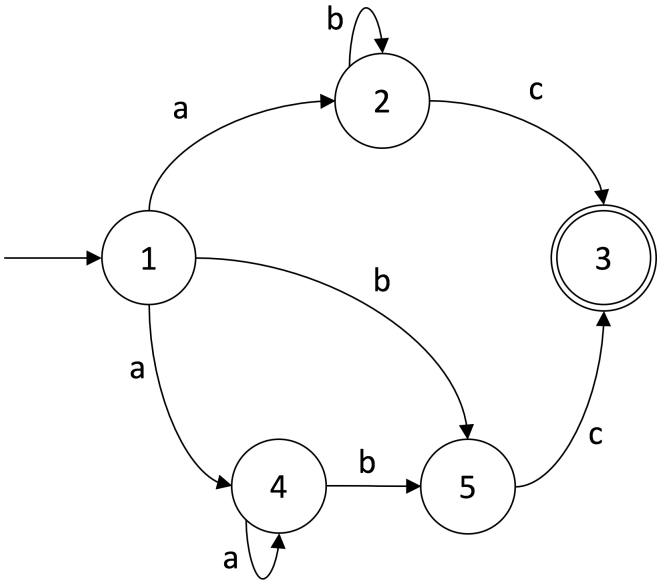
You may also use a dictionary from English to your native language.

Max points: 60
For grade 3: Min 30
For grade 4: Min 40
For grade 5: Min 50

[1]The *personal identifier* is a short phrase, a code or a brief sentence of your choice. It can be anything, but not something that can reveal your identity. The purpose of this identifier is to make it possible for you to identify your exam in case something goes wrong with the anonymous code on the exam cover (such as if it is confused with another code due to sloppy writing).

1 Lexical analysis

Consider the following NFA that defines a language over the alphabet $\{a, b, c\}$.



a) List all strings of length 5 or shorter that belong to the language. (5p)

b) Construct a regular expression that is equivalent to the NFA. Try to make the regular expression as simple as possible. (5p)

c) Construct a DFA that is equivalent to the NFA by letting each DFA state simulate a set of NFA states. Label each DFA state with the set of corresponding NFA states. Your DFA does not need to be minimal, but it should be easy to read (avoid crossing edges if possible).

Hint! Make sure your DFA accepts all the strings you listed in a). (5p)

2 Context-Free Grammars

Consider the following context-free grammar for email addresses:

p_0 : `start` $\rightarrow$ `address EOF`
p_1 : `address` $\rightarrow$ `name "@" name "." ID`
p_2 : `name` $\rightarrow$ `ID`
p_3 : `name` $\rightarrow$ `name "." ID`

where `EOF` is the terminal symbol for end-of-file, and `ID` is a terminal symbol corresponding to a token defined as `ID = [A-Za-z]+`

a) Construct a parse tree following the above grammar and that uses each production at least once. (5p)

b) Construct an equivalent grammar on EBNF form with as few nonterminals as possible. (Recall that EBNF allows the use of alternatives, repetition, optionals, and parentheses.)

(5p)

c) The original grammar is not LL(1). Show this by constructing its LL(1) table. The table should have one column for each of the terminal symbols.

(5p)

d) Construct an equivalent grammar that is LL(1). The grammar should be on canonical form, just like the original grammar. If you make more than one transformation, show each transformation as a separate step (to maximize your chances of getting points even if parts of your solution is wrong).

Hint! Check that your resulting grammar is LL(1). If you get stuck, see if you can switch the order of some symbols without changing the language.

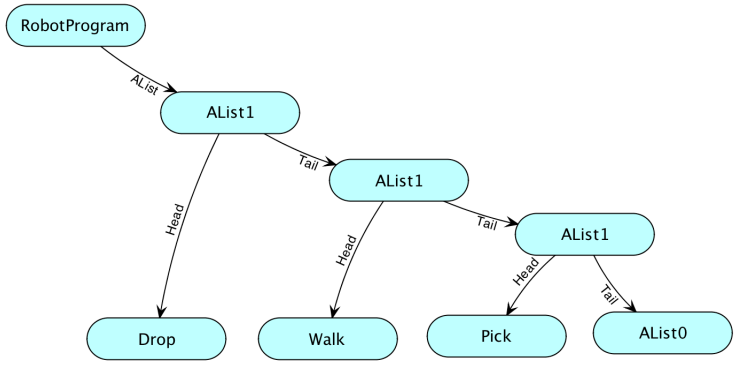
(5p)

3 Program analysis

The following abstract grammar defines a robot language with instructions Walk, Pick, and Drop. At a Pick action, the robot picks up an item, but it can hold at most three items, so if it already has three, the Pick action has no effect. The Drop action drops one of the items, but has no effect if the robot has no items. At the Walk action, the robot takes a step forward. The actions are arranged in a sequence, using AList nodes, where AList0 is an empty list, and AList1 is a list with at least one action.

```
RobotProgram ::= AList;
abstract AList;
AList0 : AList;
AList1 : AList ::= Head:Action Tail:AList;
abstract Action;
Drop : Action;
Pick : Action;
Walk : Action;
```

The figure below shows an example robot program where the robot does a Drop, a Walk, and a Pick action. Initially, the robot has no items, so after executing this sequence it has one item left.



a) Construct an attribute grammar that defines two integer attributes `prevItems()` and `items()` for Action. The values should be the number of items that the robot holds prior to and after executing the action, respectively. In the example above, the value of `items()` for Drop and Walk would be 0, and the value for Pick would be 1. The values for `prevItems()` would be 0 for all three actions.

Your solution should use inherited and synthesized attributes, and may not use `instanceof`.

You may assume the existence of the following two methods:

```
int min(int v1, int v2) { ... } // return the minimum of v1 and v2
int max(int v1, int v2) { ... } // return the maximum of v1 and v2
```

(5p)

b) Define an integer attribute `RobotProgram.items()` whose value is the number of items the robot holds after executing all the actions. For the above program, the value would be 1. You may use attributes you defined in problem a). (5p)

c) Add an attribute `RobotProgram.failedPicks()` that uses a collection attribute to count the number of failed Pick actions in the program, i.e., Pick actions for which the robot already holds three items. You may use the attributes you defined in problem a). For the collection attribute, you may use the following type `Counter`:

```
public class Counter {
  private int count = 0;
  public void add(int increment) {
    count = count + increment;
  }
  public int count() {
    return count;
  }
}
```

(5p)

Turn page for problem 4

4 Code generation and run-time systems

Consider the following recursive program computing fibonacci numbers in a C-like language:

```
int fib(int n) {
  if ( n <= 1 ) // ** PC **
    return n;
  return fib(n-1) + fib(n-2);
}
void main() {
  int s = fib(3);
  ...
}
```

a) A compiler for the language generates unoptimized code that pushes temporaries on the stack. Arguments are passed on the stack (not in registers). The return value is passed in the `rax` register.

Write down the x86 code generated by the compiler for the `fib` method.

Use only the instructions on the x86 Cheat Sheet. Use `rbp` as frame pointer and `rsp` as stack pointer. You are encouraged to comment your code to help us understand your intention. For simplicity and readability, you may leave out the characters `q`, `%`, and `,` in the code. For example, you may write `add $8 rax` instead of `addq $8, %rax`. (5p)

b) Draw the situation on the stack when the execution has reached the location indicated by `** PC **` for the call to `fib(0)`.

Your drawing should include stack frames for `main` and `fib` activations, stack pointer, frame pointer, dynamic links, return addresses, arguments and temporary variables. Include the actual values for dynamic links, arguments and temporary variables according to what is known at that point in the execution.

Mark each frame with what activation it is, e.g., `fib(3)`. Mark arguments with *arg* and temporaries with *temp*. The drawing should be consistent with your code from problem 4 a). (5p)