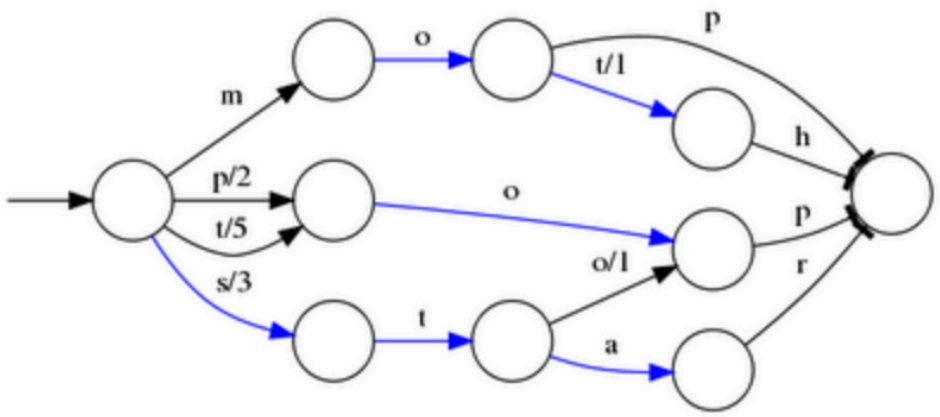
Friday, December 3, 2010

Using Finite State Transducers in Lucene

FSTs are finite-state machines that map a term (byte sequence) to an arbitrary output. They also look cool:

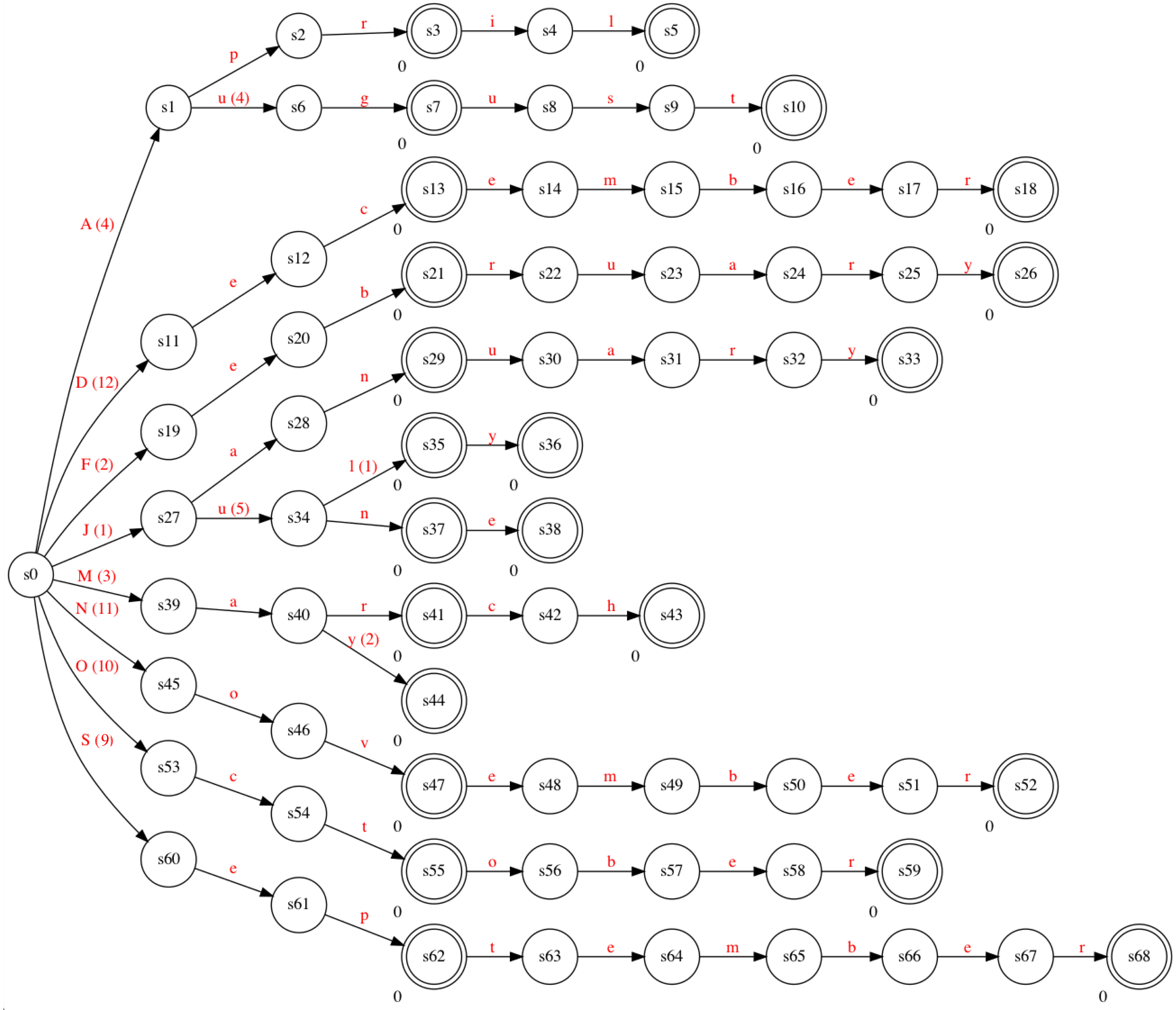


That FST maps the sorted words *mop*, *moth*, *pop*, *star*, *stop* and *top* to their ordinal number (0, 1, 2, ...). As you traverse the arcs, you sum up the outputs, so *stop* hits 3 on the **s** and 1 on the **o**, so its output ordinal is 4. The outputs can be arbitrary numbers or byte sequences, or combinations, etc. -- it's pluggable.

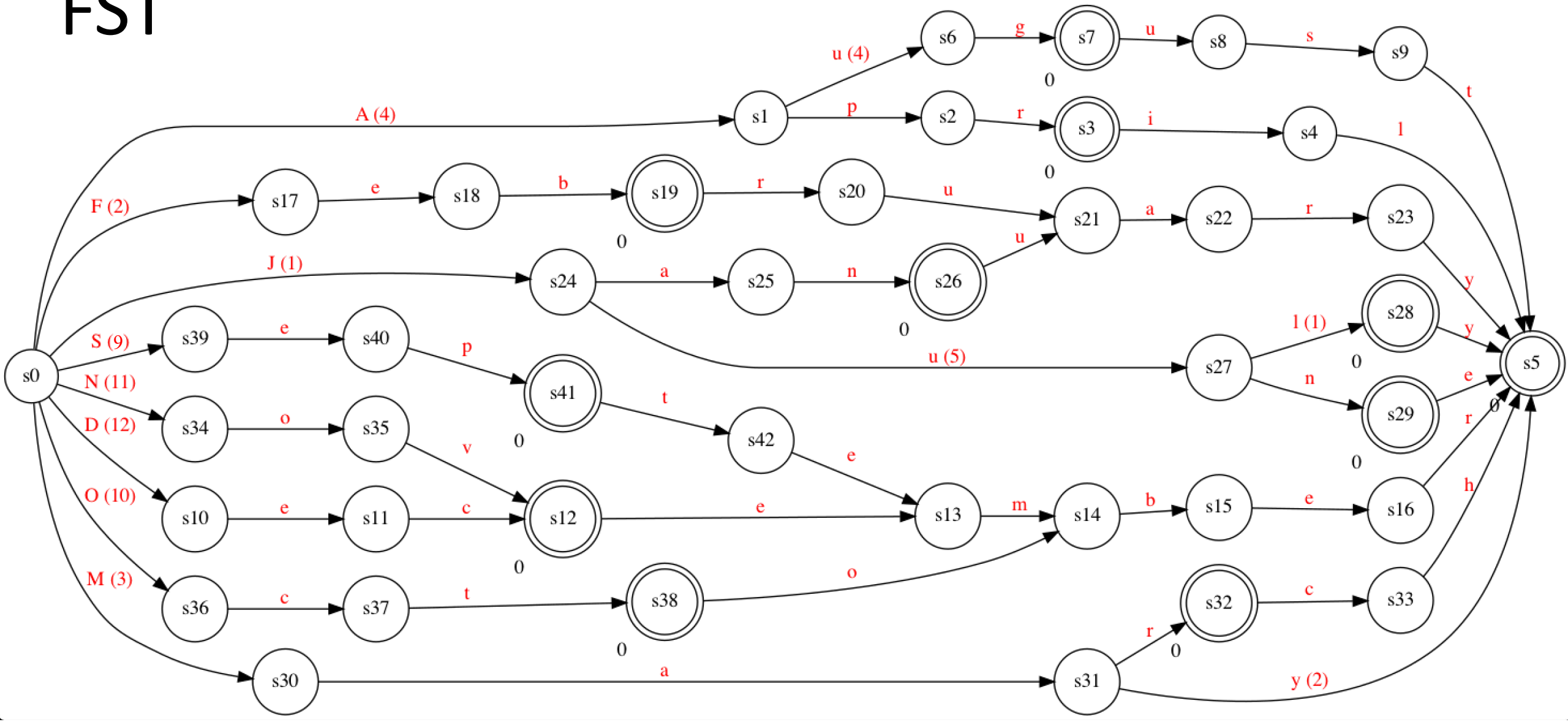
Essentially, an FST is a SortedMap<ByteSequence,SomeOutput>, if the arcs are in sorted order. With the right representation, it requires far less RAM than other SortedMap implementations, but has a higher CPU cost during lookup. The low memory footprint is vital for Lucene since an index can easily have many millions (sometimes, billions!) of unique terms.

January, 1
Jan, 1
February, 2
Feb, 2
March, 3
Mar, 3
April, 4
Apr, 4
May, 5
June, 6
Jun, 6
July, 7
Jul, 7
August, 8
Aug, 8
September, 8
Sep, 8
October, 10
Oct, 10
November, 11
Nov, 11
December, 12
Dec,12

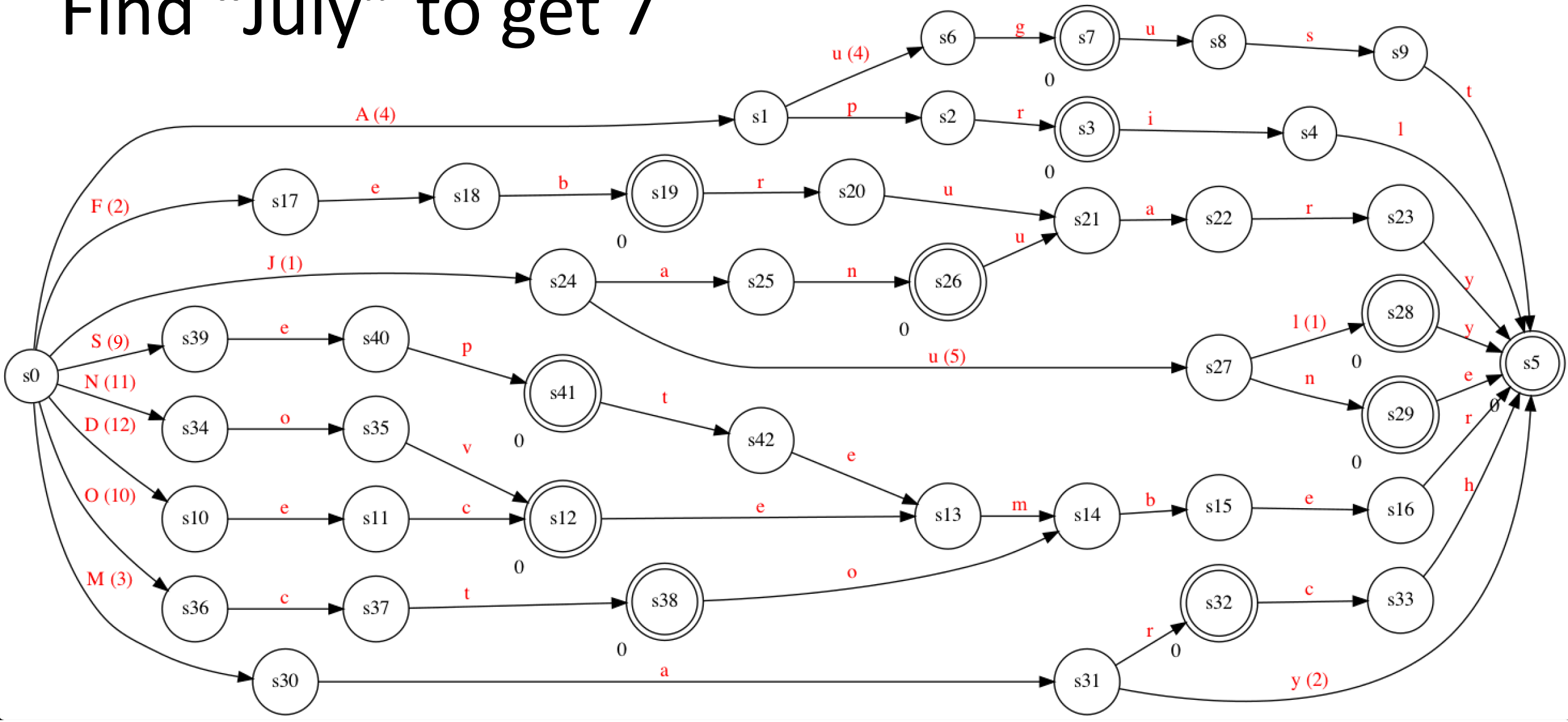
Trie


s0
A (4)
s1
p
s2
r
s3
i
s4
l
s5
0
0
u (4)
s6
g
s7
u
s8
s
s9
t
s10
0
0
D (12)
s11
e
s12
c
s13
e
s14
m
s15
b
s16
e
s17
r
s18
0
0
F (2)
s19
e
s20
b
s21
r
s22
u
s23
a
s24
r
s25
y
s26
0
0
J (1)
s27
a
s28
n
s29
u
s30
a
s31
r
s32
y
s33
0
0
u (5)
s34
l (1)
s35
y
s36
0
0
n
s37
e
s38
0
0
M (3)
s39
a
s40
r
s41
c
s42
h
s43
0
0
y (2)
s44
0
N (11)
s45
o
s46
v
s47
e
s48
m
s49
b
s50
e
s51
r
s52
0
0
O (10)
s53
c
s54
t
s55
o
s56
b
s57
e
s58
r
s59
0
0
S (9)
s60
e
s61
p
s62
t
s63
e
s64
m
s65
b
s66
e
s67
r
s68
0
0

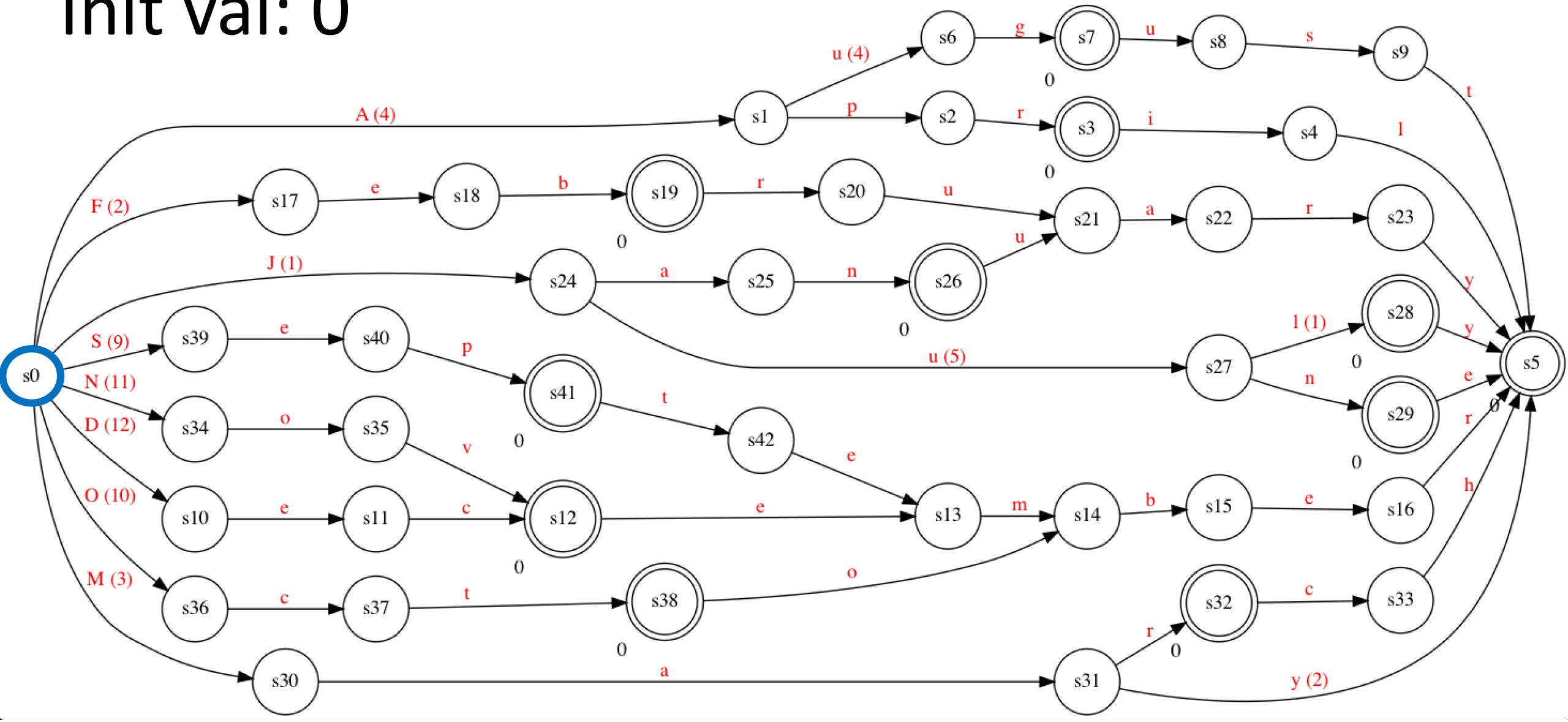
FST


s0
A (4)
s1
u (4)
s6
g
s7
u
s8
s
s9
t
p
s2
r
s3
i
s4
l
F (2)
s17
e
s18
b
s19
r
s20
u
s21
a
s22
r
s23
y
J (1)
s24
a
s25
n
s26
u
S (9)
s39
e
s40
p
s41
t
s42
e
s27
l (1)
s28
y
u (5)
s5
N (11)
s34
o
s35
v
n
s29
e
D (12)
r
O (10)
s10
e
s11
c
s12
e
s13
m
s14
b
s15
e
s16
h
M (3)
s36
c
s37
t
s38
o
s32
c
s33
s30
a
s31
r
y (2)

Find “July” to get 7



Init val: 0


s0
A (4)
s1
u (4)
s6
g
s7
u
s8
s
s9
t
p
s2
r
s3
i
s4
l
F (2)
s17
e
s18
b
s19
r
s20
u
s21
a
s22
r
s23
y
J (1)
s24
a
s25
n
s26
u
S (9)
s39
e
s40
p
s41
t
s42
e
s27
l (1)
s28
y
u (5)
s5
N (11)
s34
o
s35
v
n
s29
e
D (12)
r
O (10)
s10
e
s11
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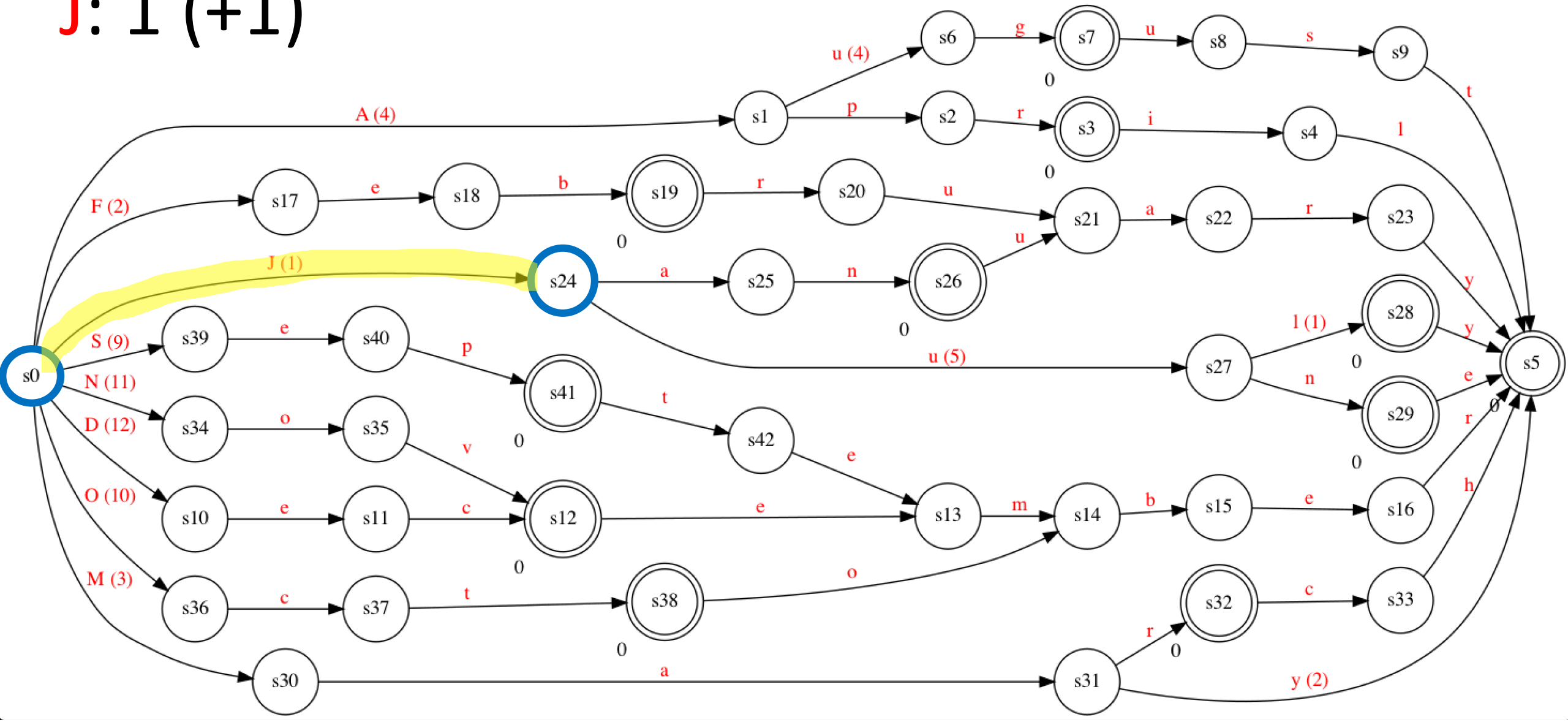
s12
e
s13
m
s14
b
s15
e
s16
h
M (3)
s36
c
s37
t
s38
o
s32
c
s33
s30
a
s31
r
y (2)

J: 1 (+1)


s0
A (4)
F (2)
J (1)
S (9)
N (11)
D (12)
O (10)
M (3)
s1
s2
s3
s4
s5
s6
s7
s8
s9
u (4)
p
r
i
t
l
g
u
s
0
s17
s18
s19
s20
s21
s22
s23
e
b
r
u
a
r
y
s24
s25
s26
a
n
u
u (5)
s27
s28
s29
l (1)
n
y
e
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s39
s40
s41
s42
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s35
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s30
s31
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b
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c
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a
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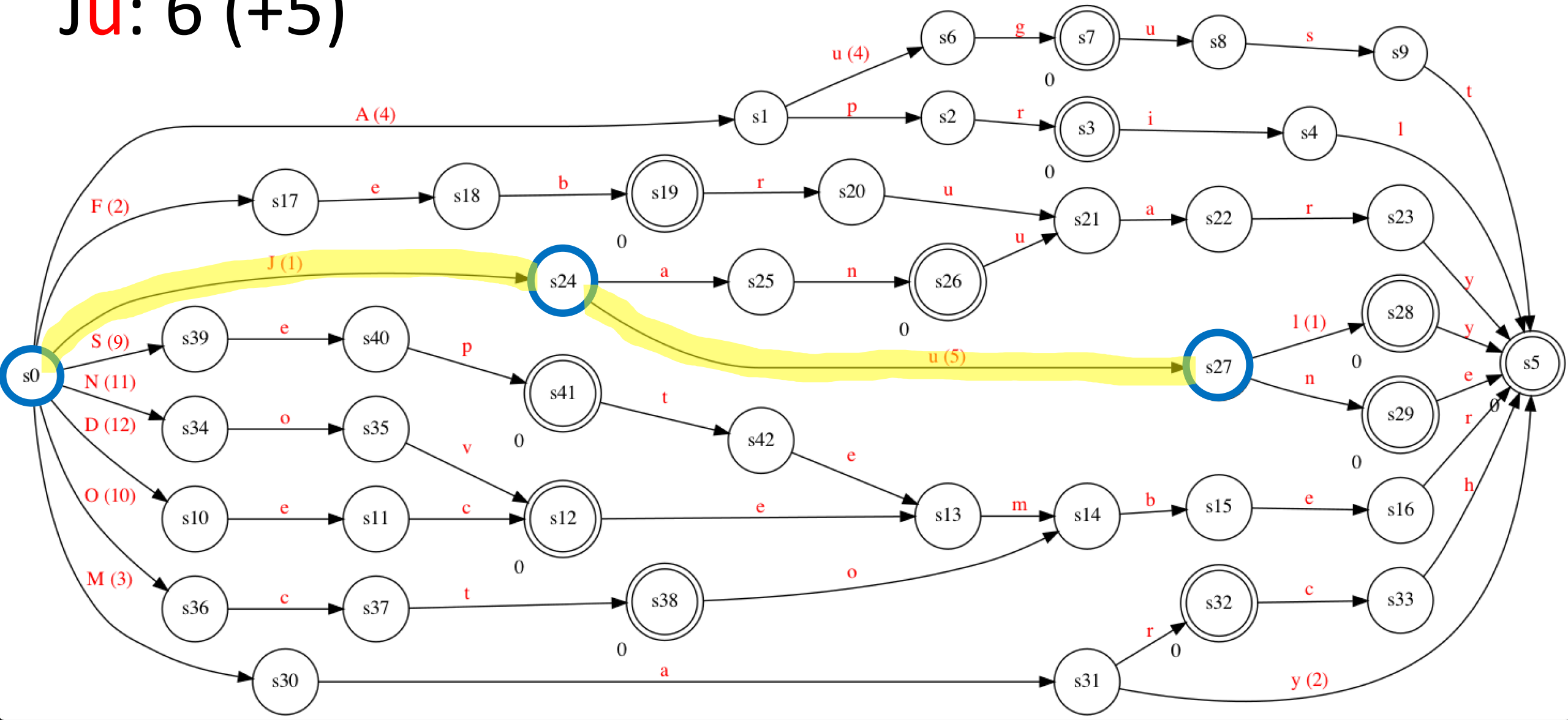
y (2)

Ju: 6 (+5)


s0
A (4)
F (2)
J (1)
S (9)
N (11)
D (12)
O (10)
M (3)
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u (4)
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y
J (1)
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S (9)
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N (11)
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D (12)
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O (10)
e
c
M (3)
c
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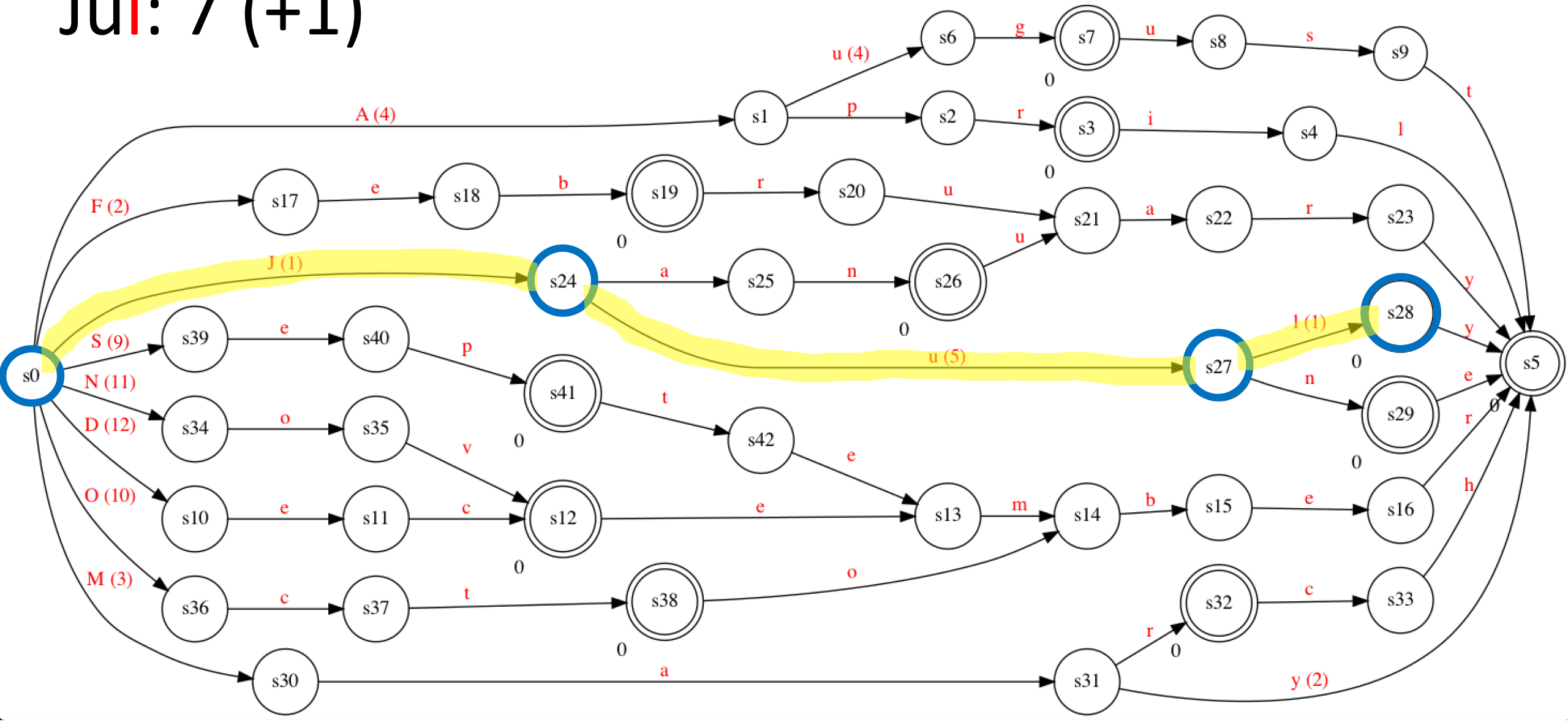
e
m
b
e
r
h
o
a
y (2)
l (1)
n
0

Jul: 7 (+1)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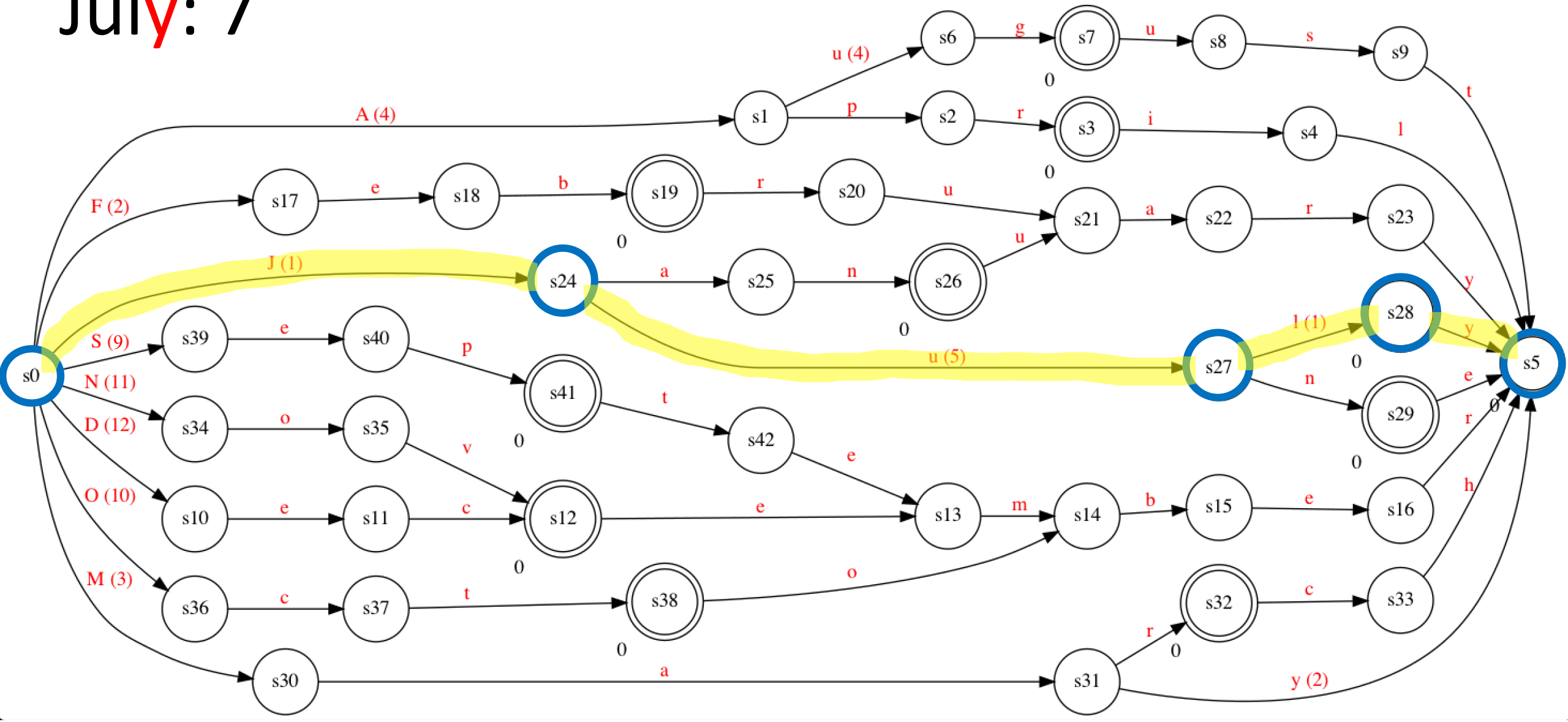
s38
s39
s40
s41
s42
A (4)
F (2)
J (1)
S (9)
N (11)
D (12)
O (10)
M (3)
u (4)
u (5)
l (1)
y (2)
0

July: 7


s0
A (4)
s1
u (4)
s6
g
s7
u
s8
s
s9
t
p
s2
r
s3
i
s4
l
F (2)
s17
e
s18
b
s19
r
s20
u
s21
a
s22
r
s23
y
J (1)
s24
a
s25
n
s26
u
S (9)
s39
e
s40
p
s41
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s42
e
s27
l (1)
s28
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u (5)
N (11)
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D (12)
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s11
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s13
m
s14
b
s15
e
s16
r
h
O (10)
M (3)
s36
c
s37
t
s38
o
s32
c
s33
r
s30
a
s31
y (2)

Tree Structure

Contains pointers and containers

Can’t serialize it easily to a file…

```
// Tree Structure
struct State {
  struct Transition {
    char arc;
    State* state;
    uint32_t output;
  }

  bool final;
  std::vector<Transition> transitions;
}

State* root;

// Byte Code
struct Ope {
  char arc;
  bool last_transition;
  bool final;
  uint32_t next_address;
  uint32_t output;
};

std::vector<Ope> byte_code;
```

Byte Code

Just primitive values

Can directly save it to file
Zero loading time!

Byte code

```
[master] ~/Projects/cpp-fstlib/demo$ xxd months.fst
00000000: 806c 0669 0347 8074 0673 0363 6707 846b  .l.i.G.t.s.cg..k
00000010: 8b70 0080 4623 c36d 0323 e723 8079 0643  .p..F#.m.#.#.y.C
00000020: 8363 43c7 2385 626e 0780 7906 8026 6e07  .cC.#.bn..y..&n.
00000030: 8185 6c0c 8c82 8583 6880 6806 e382 8079  ..l.....h.h....y
00000040: 0e85 4483 ab76 066f 03b3 6f02 7407 e3b7  ..D..v.o..o.t...
00000050: 2274 0370 0723 8953 0b8a 8b4f 088b 954e  "t.p.#.S...O...N
00000060: 0883 9e4d 0881 ada8 82c4 4608 8cd1 4408  ...M......F...D.
00000070: 84de 4108 0004 080c 0f13 171b 88fe 0000  ..A.............
00000080: 0100 7d00 0000 0065 7275 614a 6263 0000  ..}....eruaJbc..
00000090: 0000 0000 0000                           ......
```

Byte code dump

Byte code records are stored in backward order!

N: No next address. Just move to next record
F: Final state (or ‘accepted’)
L: Last transition in a state

```
[master] ~/Projects/cpp-fstlib/demo$ ./fst dump months -f csv
Address Arc     N F L   NxtAddr Output  StOuts  Size
------- ---     ----- - ------- ------  ------  ----
2       l         * -   x                       3
4       i       ↑   -                           2
5       r       ↑ * -                           1
8       t         * -   x                       3
10      s       ↑   -                           2
11      u       ↑   -                           1
13      g       ↑ * -                           2
15      u       ↑   -           4               2
18      p                 5                     3
20      r         * -   x                       2
21      e       ↑   -                           1
22      b       ↑   -                           1
24      m       ↑   -                           2
25      e       ↑   -                           1
26      c       ↑ * -                           1
27      e       ↑   -                           1
30      y         * -   x                       3
31      r       ↑   -                           1
32      a       ↑   -                           1
33      u       ↑   -                           1
34      r       ↑   -                           1
35      b       ↑ * -                           1
36      e       ↑   -                           1
38      u                 32                    2
40      n       ↑ *                             2
43      y         *   x                         3
45      e         *   x                         2
47      n       ↑ *                             2
51      l         *   43      1                 4
53      a                 40                    2
56      u                 51      5             3
59      h         * -   x                       3
60      c       ↑   -                           1
64      y         * -   x       2               4
66      e         *             60              2
67      a       ↑   -                           1
70      v         * -   25                      3
72      o       ↑   -                           2
75      o                 22                    3
77      t       ↑ * -                           2
78      c       ↑   -                           1
80      e                 24                    2
82      t       ↑   -                           2
84      p       ↑ * -                           2
85      e       ↑   -                           1
88      S       ↑   -           9               3
92      O                 78      10            4
96      N                 72      11            4
100     M                 67      3             4
103     J                 56      1             3
107     F                 36      2             4
111     D                 27      12            4
125     A                 18      4             14
```

FST (Finite State Transducer) library

Trie-like data structure

O(M) access like std::unordered_map
Common prefix match (‘computer programming is fun.’ returns ‘computer’, ‘computer programming’)

Read-only binary database

Zero loading time when lookup
Memory-mapped file friendly
Compact (‘/usr/shared/dict/words’: 2.4M → 1.1M)

Examples that fstlib can do, but std::unordered_map cannot effectively

Keyword extraction (‘Longest common prefix search’)
Word/phrase list dictionary for full-text search library (‘Zero loading time’, ‘Compact’)

cpp-fstlib internals

Compile a source dictionary to byte code, then interpret it when searching
Incremental direct database construction without having a complete set of states on memory
Implemented based on https://blog.burntsushi.net/transducers/. Thanks for the valuable information!