Systems Software: P-Machine Example #2

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PL/0 Language

▶ The high level language used for the P-Machine

```
var product, a, b;
procedure mult;
  begin
    while a > 0 do:
      begin
        call add;
        a := a – 1;
      end;
  end;
procedure add;
  begin
    product := product + b;
  end;
end;

begin
  product := 0;
  in a;
  in b;
  call mult;
  out product;
end.
```

The compiled PL/0 language

- The previous code is compiled into the assembly language for the P-Machine

- We will go over the execution of this code while watching the state of the machine

- For this example, we are assuming the input "3" and "4" from the user

```
 0 JMP 0 21      16 LOD 1 3
 1 JMP 0 3       17 LOD 1 5
 2 JMP 0 15      18 OPR 0 2
 3 INC 0 3       19 STO 1 3
 4 LOD 1 4       20 OPR 0 0
 5 LIT 0 0       21 INC 0 6
 6 OPR 0 12      22 LIT 0 0
 7 JPC 0 14      23 STO 0 3
 8 CAL 1 15      24 IN  0 0
 9 LOD 1 4       25 STO 0 4
10 LIT 0 1       26 IN  0 0
11 OPR 0 3       27 STO 0 5
12 STO 1 4       28 CAL 0 3
13 JMP 0 4       29 LOD 0 3
14 OPR 0 0       30 OUT 0 0
15 INC 0 3       31 OPR 0 0
```

Execution

BP   SP   PC

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

Code:

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

BP   SP   PC

AR Stack

Execution

BP   SP   PC

? ? ? ? ? ?

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? ? ? ? 0

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 0 ? ?

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 0 ? ? 3

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 0 3 ?

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP	SP	PC

? ? ? 0 3 ? 4

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 0 3 4

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 0 3 4 | 0 0 29

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

| BP | SP | PC |

? ? ? 0 3 4 | 0 0 29

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP	SP	PC

? ? ? 0 3 4 | 0 0 29 3

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 0 3 4 | 0 0 29 3 0

AR Stack

```
 0 JMP 0 21      16 LOD 1 3
 1 JMP 0 3       17 LOD 1 5
 2 JMP 0 15      18 OPR 0 2
 3 INC 0 3       19 STO 1 3
 4 LOD 1 4       20 OPR 0 0
 5 LIT 0 0       21 INC 0 6
 6 OPR 0 12      22 LIT 0 0
 7 JPC 0 14      23 STO 0 3
 8 CAL 1 15      24 IN  0 0
 9 LOD 1 4       25 STO 0 4
10 LIT 0 1       26 IN  0 0
11 OPR 0 3       27 STO 0 5
12 STO 1 4       28 CAL 0 3
13 JMP 0 4       29 LOD 0 3
14 OPR 0 0       30 OUT 0 0
15 INC 0 3       31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 0 3 4 | 0 0 29 1

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 0 3 4 | 0 0 29

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 0 3 4 | 0 0 29 | 0 6 9

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

AR Stack

Code

Execution

| BP | SP | PC |

? ? ? 0 3 4 | 0 0 29 | 0 6 9 0

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 0 3 4 | 0 0 29 | 0 6 9 0 4

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 0 3 4 | 0 0 29 | 0 6 9 4

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

BP   SP   PC

? ? ? 4 3 4 | 0 0 29 | 0 6 9

Execution

BP   SP   PC

? ? ? 4 3 4 | 0 0 29

AR Stack

```
 0 JMP 0 21   16 LOD 1 3
 1 JMP 0 3    17 LOD 1 5
 2 JMP 0 15   18 OPR 0 2
 3 INC 0 3    19 STO 1 3
 4 LOD 1 4    20 OPR 0 0
 5 LIT 0 0    21 INC 0 6
 6 OPR 0 12   22 LIT 0 0
 7 JPC 0 14   23 STO 0 3
 8 CAL 1 15   24 IN  0 0
 9 LOD 1 4    25 STO 0 4
10 LIT 0 1    26 IN  0 0
11 OPR 0 3    27 STO 0 5
12 STO 1 4    28 CAL 0 3
13 JMP 0 4    29 LOD 0 3
14 OPR 0 0    30 OUT 0 0
15 INC 0 3    31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 4 3 4 | 0 0 29 3

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 4 3 4 | 0 0 29 3 1

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 4 3 4 | 0 0 29 2

AR Stack

0	JMP 0 21	16	LOD 1 3
1	JMP 0 3	17	LOD 1 5
2	JMP 0 15	18	OPR 0 2
3	INC 0 3	19	STO 1 3
4	LOD 1 4	20	OPR 0 0
5	LIT 0 0	21	INC 0 6
6	OPR 0 12	22	LIT 0 0
7	JPC 0 14	23	STO 0 3
8	CAL 1 15	24	IN 0 0
9	LOD 1 4	25	STO 0 4
10	LIT 0 1	26	IN 0 0
11	OPR 0 3	27	STO 0 5
12	STO 1 4	28	CAL 0 3
13	JMP 0 4	29	LOD 0 3
14	OPR 0 0	30	OUT 0 0
15	INC 0 3	31	OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29

AR Stack

0	JMP 0 21			16	LOD 1 3		
1	JMP 0 3			17	LOD 1 5		
2	JMP 0 15			18	OPR 0 2		
3	INC 0 3			19	STO 1 3		
4	LOD 1 4			20	OPR 0 0		
5	LIT 0 0			21	INC 0 6		
6	OPR 0 12			22	LIT 0 0		
7	JPC 0 14			23	STO 0 3		
8	CAL 1 15			24	IN 0 0		
9	LOD 1 4			25	STO 0 4		
10	LIT 0 1			26	IN 0 0		
11	OPR 0 3			27	STO 0 5		
12	STO 1 4			28	CAL 0 3		
13	JMP 0 4			29	LOD 0 3		
14	OPR 0 0			30	OUT 0 0		
15	INC 0 3			31	OPR 0 0		

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29 2

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29 2 0

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29 1

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29 | 0 6 9

AR Stack

0	JMP	0	21	16	LOD	1	3
1	JMP	0	3	17	LOD	1	5
2	JMP	0	15	18	OPR	0	2
3	INC	0	3	19	STO	1	3
4	LOD	1	4	20	OPR	0	0
5	LIT	0	0	21	INC	0	6
6	OPR	0	12	22	LIT	0	0
7	JPC	0	14	23	STO	0	3
8	CAL	1	15	24	IN	0	0
9	LOD	1	4	25	STO	0	4
10	LIT	0	1	26	IN	0	0
11	OPR	0	3	27	STO	0	5
12	STO	1	4	28	CAL	0	3
13	JMP	0	4	29	LOD	0	3
14	OPR	0	0	30	OUT	0	0
15	INC	0	3	31	OPR	0	0

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29 | 0 6 9 4

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29 | 0 6 9 4 4

AR Stack

0	JMP	0	21	16	LOD	1	3
1	JMP	0	3	17	LOD	1	5
2	JMP	0	15	18	OPR	0	2
3	INC	0	3	19	STO	1	3
4	LOD	1	4	20	OPR	0	0
5	LIT	0	0	21	INC	0	6
6	OPR	0	12	22	LIT	0	0
7	JPC	0	14	23	STO	0	3
8	CAL	1	15	24	IN	0	0
9	LOD	1	4	25	STO	0	4
10	LIT	0	1	26	IN	0	0
11	OPR	0	3	27	STO	0	5
12	STO	1	4	28	CAL	0	3
13	JMP	0	4	29	LOD	0	3
14	OPR	0	0	30	OUT	0	0
15	INC	0	3	31	OPR	0	0

Code

Execution

BP   SP   PC

? ? ? 4 2 4 | 0 0 29 | 0 6 9 8

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 8 2 4 | 0 0 29 | 0 6 9

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution


```
BP      SP      PC
```

```
? ? ? 8 2 4 | 0 0 29
```
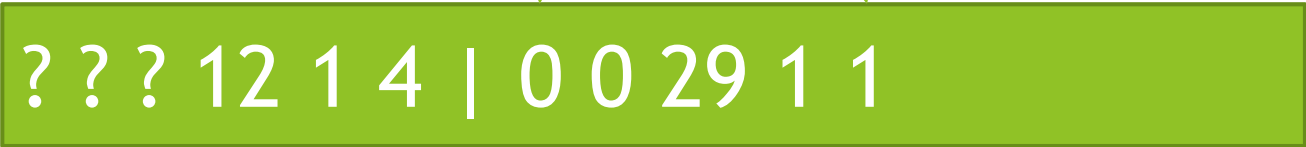
AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Flash Forward a Couple Dozen Instructions…

Execution

BP   SP   PC

? ? ? 12 1 4 | 0 0 29

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 12 1 4 | 0 0 29 1

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 12 1 4 | 0 0 29 1 1

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

? ? ? 12 1 4 | 0 0 29 0

AR Stack

0	JMP	0	21	
1	JMP	0	3	
2	JMP	0	15	
3	INC	0	3	
4	LOD	1	4	
5	LIT	0	0	
6	OPR	0	12	
7	JPC	0	14	
8	CAL	1	15	
9	LOD	1	4	
10	LIT	0	1	
11	OPR	0	3	
12	STO	1	4	
13	JMP	0	4	
14	OPR	0	0	
15	INC	0	3	
16	LOD	1	3	
17	LOD	1	5	
18	OPR	0	2	
19	STO	1	3	
20	OPR	0	0	
21	INC	0	6	
22	LIT	0	0	
23	STO	0	3	
24	IN	0	0	
25	STO	0	4	
26	IN	0	0	
27	STO	0	5	
28	CAL	0	3	
29	LOD	0	3	
30	OUT	0	0	
31	OPR	0	0	

Code

Execution

BP   SP   PC
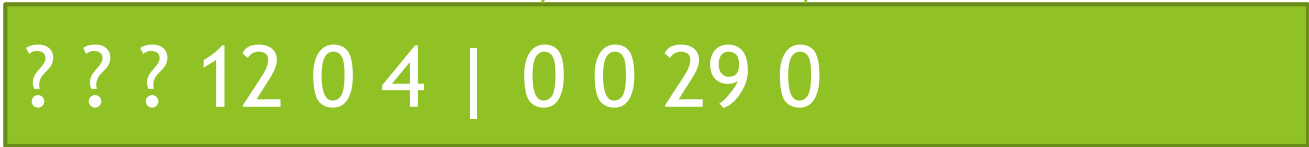
? ? ? 12 0 4 | 0 0 29

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 12 0 4 | 0 0 29
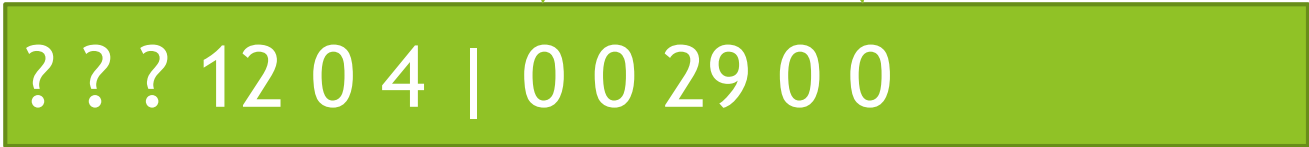
AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 12 0 4 | 0 0 29 0
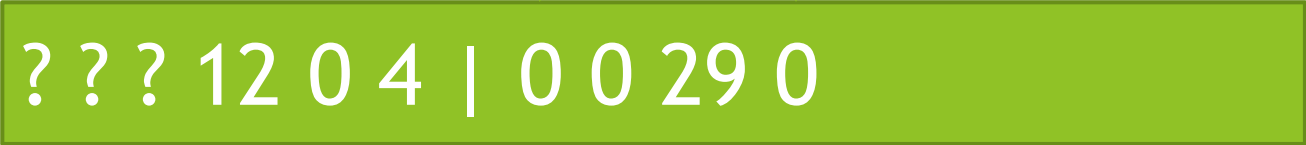
AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP	SP	PC

? ? ? 12 0 4 | 0 0 29 0 0

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 12 0 4 | 0 0 29 0
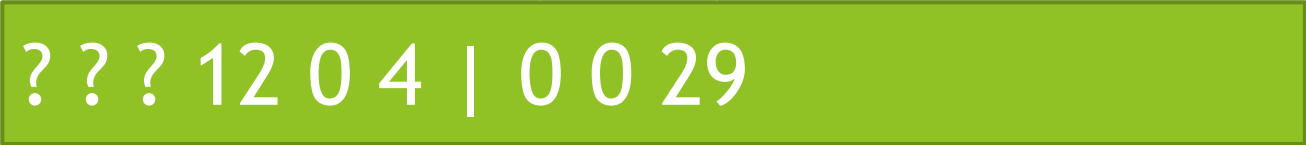
AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP	SP	PC

? ? ? 12 0 4 | 0 0 29

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 12 0 4

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 12 0 4 12

AR Stack

```
 0 JMP 0 21    16 LOD 1 3
 1 JMP 0 3     17 LOD 1 5
 2 JMP 0 15    18 OPR 0 2
 3 INC 0 3     19 STO 1 3
 4 LOD 1 4     20 OPR 0 0
 5 LIT 0 0     21 INC 0 6
 6 OPR 0 12    22 LIT 0 0
 7 JPC 0 14    23 STO 0 3
 8 CAL 1 15    24 IN  0 0
 9 LOD 1 4     25 STO 0 4
10 LIT 0 1     26 IN  0 0
11 OPR 0 3     27 STO 0 5
12 STO 1 4     28 CAL 0 3
13 JMP 0 4     29 LOD 0 3
14 OPR 0 0     30 OUT 0 0
15 INC 0 3     31 OPR 0 0
```

Code

Execution

BP   SP   PC

? ? ? 12 0 4

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code

Execution

BP   SP   PC

AR Stack

0 JMP 0 21	16 LOD 1 3
1 JMP 0 3	17 LOD 1 5
2 JMP 0 15	18 OPR 0 2
3 INC 0 3	19 STO 1 3
4 LOD 1 4	20 OPR 0 0
5 LIT 0 0	21 INC 0 6
6 OPR 0 12	22 LIT 0 0
7 JPC 0 14	23 STO 0 3
8 CAL 1 15	24 IN 0 0
9 LOD 1 4	25 STO 0 4
10 LIT 0 1	26 IN 0 0
11 OPR 0 3	27 STO 0 5
12 STO 1 4	28 CAL 0 3
13 JMP 0 4	29 LOD 0 3
14 OPR 0 0	30 OUT 0 0
15 INC 0 3	31 OPR 0 0

Code