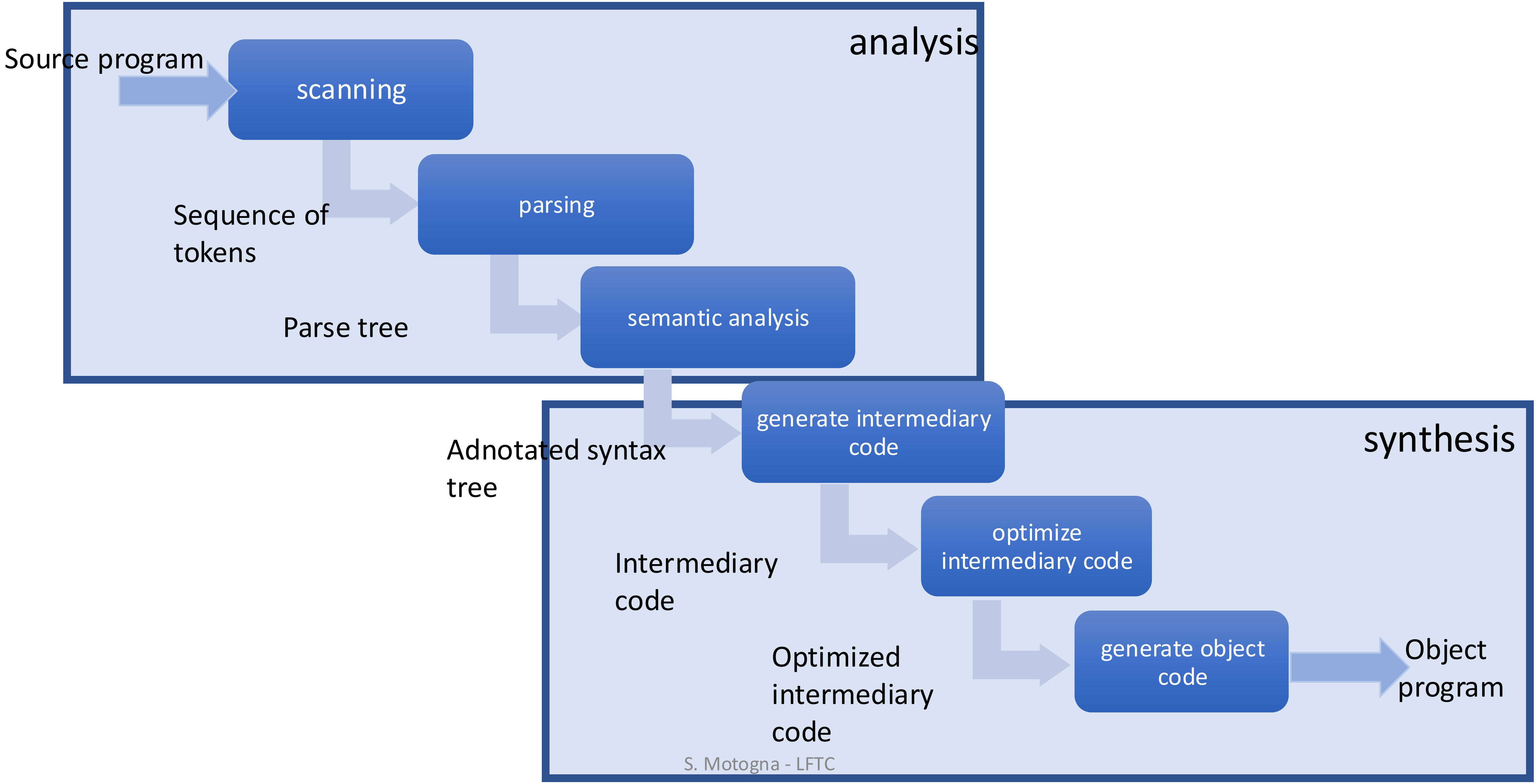
Course 12

Structure of compiler



Generate object code

= translate intermediary code statements into statements of object code (machine language)

- Depend on “machine”: architecture and OS

Computer with accumulator

- A **stack machine** consists of:
- a stack for storing and manipulating values (store subexpressions and results)
- Accumulator – to execute operation
- 2 types of statements:
  - move and copy values in and from head of stack to accumulator
  - Operations on stack head, functioning as follows: operands are popped from stack, execute operation and then put the result in stack

Example: 4 * (5+1)

Code	acc	stack
acc ← 4	4	<>
push acc	4	<4>
acc ← 5	5	<4>
push acc	5	<5,4>
acc ← 1	1	<5,4>
acc ← acc + head	6	<5,4>
pop	6	<4>
acc ← acc * head	24	<4>
pop	24	<>

Computer with registers

- Registers +
- Memory

- Instructions:
  - LOAD v,R – load value **v** in register **R**
  - STORE R,v – put value **v** from register **R** in memory
  - ADD R1,R2 – add to the value from register **R1**, value from register **R2** and store the result in **R1** (initial value is lost!)

2 aspects:

- Register allocation – way in which variable are stored and manipulated;

- Instruction selection – way and order in which the intermediary code statements are mapped to machine instructions

Remarks:

1. A register can be available or occupied =>

   VAR(R) = set of variables whose values are stored in register R

2. For every variable, the place (register, stack or memory) in which the current value of the value exists=>

   MEM(x)= set of locations in which the value of variable x exists (will be stored in Symbol Table)

Example: F := A ∗ B – (C + B) ∗ (A * B)

Intermediary code	Object code	VAR	MEM
		VAR(R0) = {} VAR(R1) = {}	
(1) T1 = A * B			
(2) T2 = C + B			
(3) T3 = T2 * T1			
(4) F:= T1 – T3			

Example: $F := A * B - (C + B) * (A * B)$

Intermediary code	Object code	VAR	MEM
		VAR(R0) = {} VAR(R1) = {}	
(1) T1 = A * B	LOAD A, R0 MUL R0, B	VAR(R0) = {A} VAR(R0) = {T1}	MEM(T1) = {R0}
(2) T2 = C + B			
(3) T3 = T2 * T1			
(4) F:= T1 – T3			

Example: F := A * B – (C + B) * (A * B)

Intermediary code	**Object code**	**VAR**	**MEM**
		VAR(R0) = {} VAR(R1) = {}	
(1) T1 = A * B	LOAD A, R0 MUL R0, B	VAR(R0) = {T1}	MEM(T1) = {R0}
(2) T2 = C + B	LOAD C, R1 ADD R1, B	VAR(R1) = {T2}	MEM(T2) = {R1}
(3) T3 = T2 * T1			
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(2) T2 = C + B	LOAD C, R1 ADD R1, B	VAR(R1) = {T2}	MEM(T2) = {R1}
(3) T3 = T2 * T1	MUL R1,R0	VAR(R1) = {T3}	MEM(T2) = {} MEM(T3) = {R1}
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Example: F := A ∗ B – (C + B) ∗ (A * B)

Intermediary code	Object code	VAR	MEM
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(1) T1 = A * B	LOAD A, R0 MUL R0, B	VAR(R0) = {T1}	MEM(T1) = {R0}
(2) T2 = C + B	LOAD C, R1 ADD R1, B	VAR(R1) = {T2}	MEM(T2) = {R1}
(3) T3 = T2 * T1	MUL R1,R0	VAR(R1) = {T3}	MEM(T2) = {} MEM(T3) = {R1}
(4) F:= T1 – T3	SUB R0,R1 STORE RO, F	VAR(R0) = {F} VAR(R1) = {}	MEM(T1) = {} MEM(F) = {R0, F}

More about Register Allocation

- Registers – **limited resource**
- Registers – perform operations / computations
- Variables **much more** than registers

IDEA: *assigning a large number of variables to a reduced number of registers*

Live variables

- Determine the number of variables that are live (used)

Example:

a = b + c

d = a + e

e = a + c

	op	op1	op2	rez
1	+	b	c	a
2	+	a	e	d
3	+	a	c	e

	1	2	3
a	x	x	x
b	x		
c	x	x	x
d		x	
e		x	x

Graph coloring allocation (Chaitin a.o. 1982)

- Graph:
  - nodes = live variables that should be allocated to registers
  - edges = live ranges simultaneously live

Register allocation = graph coloring: colors (registers) are assigned to the nodes such that two nodes connected by an edge do not receive the same color

Disadvantage:

- NP complete problem

Linear scan allocation (Poletto a.o., 1999)

- determine all live range, represented as an interval
- intervals are traversed chronologically
- greedy algorithm

Advantage: speed – code is generated faster (speed in code generation)

Disadvantage: generated code is slower (NO speed in code execution)

Instruction selection

Example: F := A ∗ B – (C + B) ∗ (A * B)

Intermediary code	Object code	VAR	MEM
		VAR(R0) = {} VAR(R1) = {}	
(1) T1 = A * B	LOAD A, R0 MUL R0, B	VAR(R0) = {T1}	MEM(T1) = {R0}
(2) T2 = C + B	LOAD C, R1 ADD R1, B STORE R0,T1	VAR(R1) = {T2}	MEM(T2) = {R1}
(3) T3 = T2 * T1	MUL R1,R0 MUL R0,R1	VAR(R1) = {T3}	MEM(T2) = {} MEM(T3) = {R1}
(4) F:= T1 – T3	LOAD T1,R1		

Decide which register to use for an instruction

Turing Machines

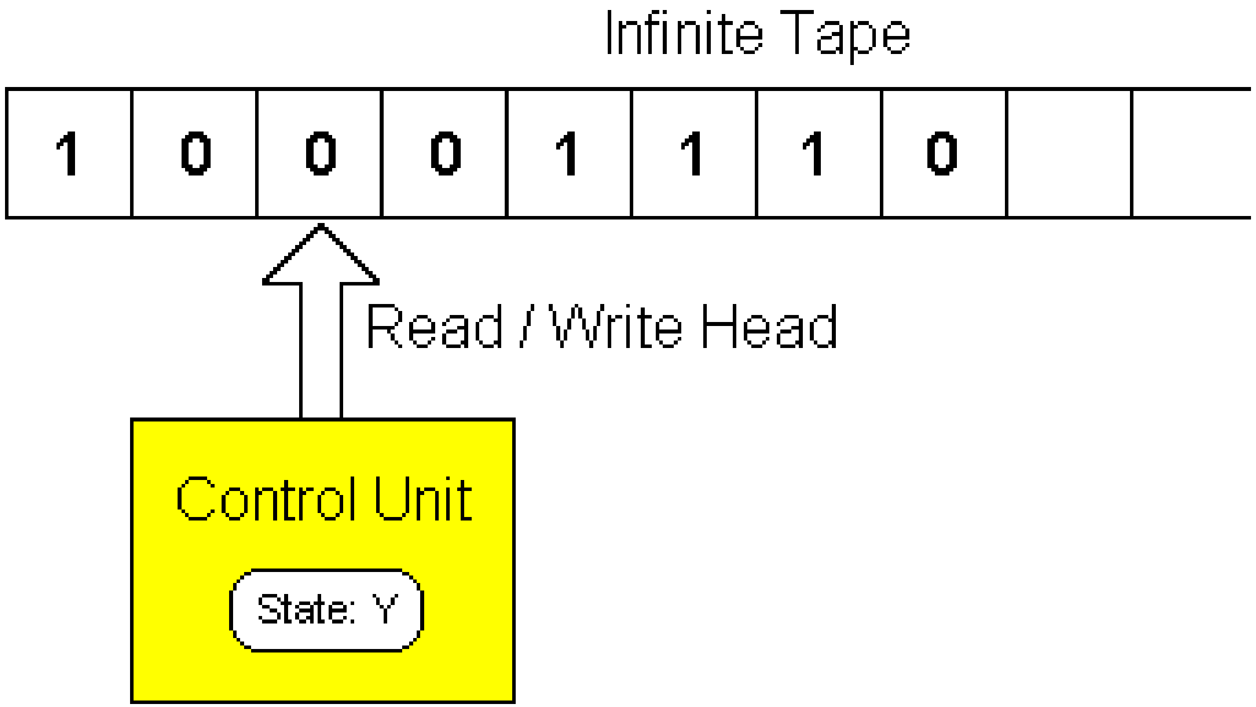
Alan Turing

- Enigma (criptography)
- Turing test
- Turing machine (1937)

Turing Machine

- Mathematical model for computation
- Abstract machine
- Can simulate any algorithm

Turing Machine



- Input band (infinite) divided into cells
- Reading head
- Control Unit: states
- Transitions / moves

Turing machine – definition

7-tuple $M = (Q, \boldsymbol{\Gamma}, b, \boldsymbol{\Sigma}, \boldsymbol{\delta}, q_0, F)$ where:

- Q – finite set of states
- $\boldsymbol{\Gamma}$ - alphabet (finite set of band symbols)
- $b \in \boldsymbol{\Gamma}$ - blank (symbol)
- $\boldsymbol{\Sigma} \subseteq \boldsymbol{\Gamma} \setminus \{b\}$ – input alphabet
- $\boldsymbol{\delta} : (Q \setminus F) \times \boldsymbol{\Gamma} \rightarrow Q \times \boldsymbol{\Gamma} \times \{L,R\}$ –transition function
- $q_0 \in Q$ – initial state
- $F \subseteq Q$ – set of final states

L = left
R = right

Example – palindrome over {0,1}

- 001100, 00100, 101101 a.s.o. accepted
- 00110, 1011 a.s.o. not accepted

$$\underline{0}0110\underline{0}$$

Example – palindrome over {0,1}

	0	1	b
q_0	(p_1,b,R)	(p_2,b,R)	(q_f,b,R)
p_1	$(p_1,0,R)$	$(p_1,1,R)$	(q_1,b,L)
p_2	$(p_2,0,R)$	$(p_2,1,R)$	(q_2,b,L)
q_1	(q_r,b,L)		(q_f,b,R)
q_2		(q_r,b,L)	(q_f,b,R)
q_r	$(q_r,0,L)$	$(q_r,1,L)$	(q_0,b,R)
q_f			

Delete 0 in left side; search 0 in right side

Delete 1 in left side; search 1 in right side

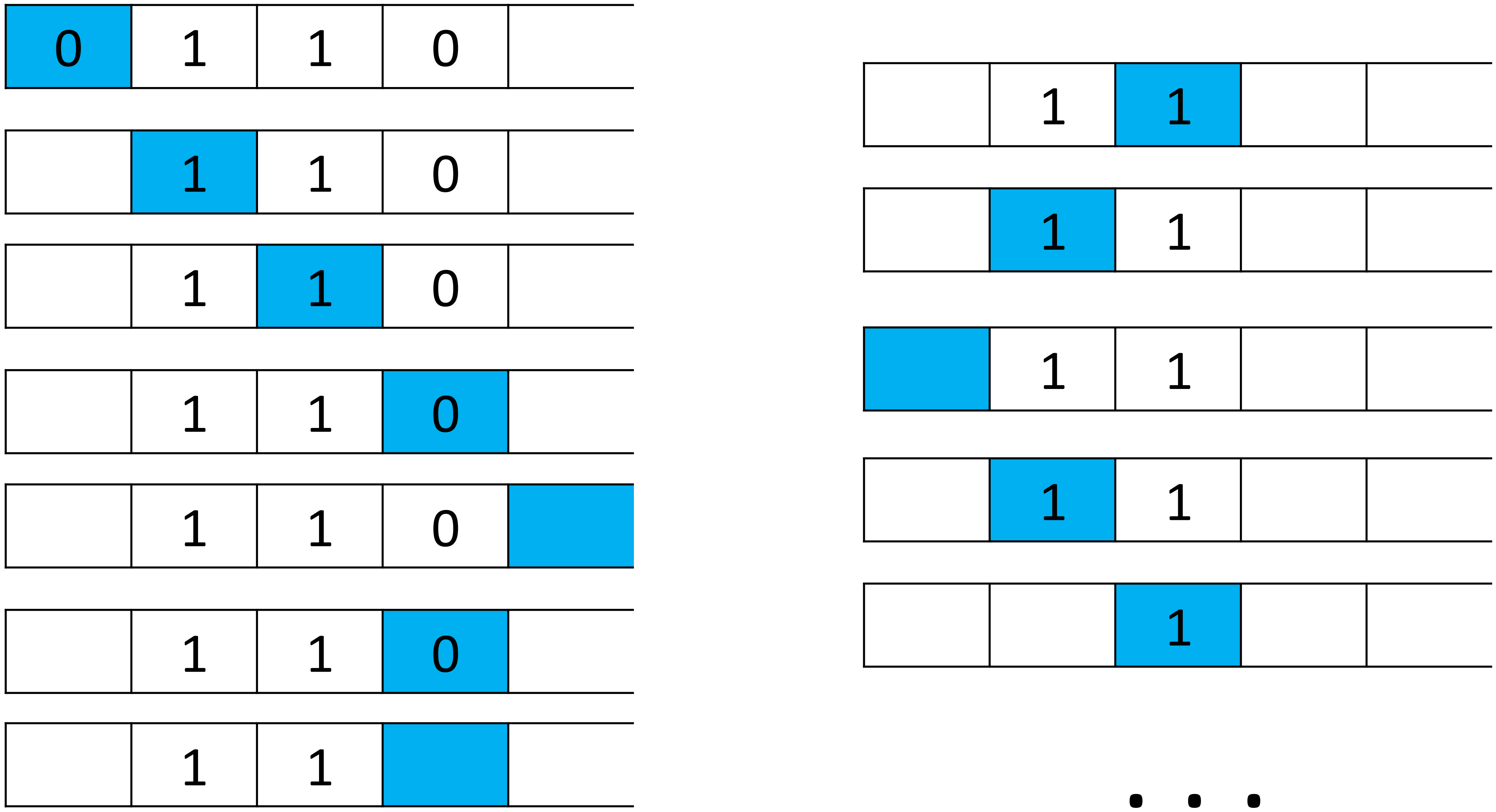
On right is 0 or 1?

Shift right

q_1 and q_2 – process 0 and 1 on the right

qf –final state

0110



$(q_0,\underline{0}110) \mid\!- (p_1, \underline{1}10) \mid\!- (p_1, 1\underline{1}0)$

$\mid\!- (p_1, 11\underline{0}) \mid\!- (p_1, 110\underline{b}) \mid\!- (q_1, 11\underline{0})$

$\mid\!- (q_r, 1\underline{1}) \mid\!- (q_r, \underline{1}1) \mid\!- (q_r, \underline{b}11)$

$\mid\!- (q_0, \underline{1}1) \mid\!- \ . \ . \ .$

	0	1	b
q_0	(p_1,b,R)	(p_2,b,R)	(q_f,b,R)
p_1	$(p_1,0,R)$	$(p_1,1,R)$	(q_1,b,L)
p_2	$(p_2,0,R)$	$(p_2,1,R)$	(q_2,b,L)
q_1	(q_r,b,L)		(q_f,b,R)
q_2		(q_r,b,L)	(q_f,b,R)
q_r	$(q_r,0,L)$	$(q_r,1,L)$	(q_0,b,R)
q_f			

https://turingmachinesimulator.com

Finite Automata & Turing Machine

- Simple models for computation
- Input band & input alphabet
- Q – finite number of states
- Transition function – determined by state & symbol

Finite Automata vs Turing Machine

- Read from input band
- Reading head - move to the right
- Finite tape – sequence
- Accept: yes/no

- Read and write on input band
- Reading head - move to the right or left
- Infinite tape
- Also compute