Teaching Programming: The Importance of Dry Running Programs

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Linked resources available at
teachinglondoncomputing.org/dryrun/

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What do I mean by Dry Runs?

- Acting as a ‘computer’
  - in the original sense
  - of a human who is following an algorithm
- ‘Unplugged’ activities
  - away from a computer / compiler
- Working out in detail and step by step what a program does
  - on paper **drawing tables**
  - **acting out computation** / “compiling” on to humans

Why are these activities vital?

- Focus on semantics (meaning) not syntax (spelling)
  - understanding **what constructs do** not just rote learning how to write them
- Develops **logical thinking**
- Develops **attention to detail**
- Allows teacher to quickly **identify misconceptions** and faulty mental models
- Helps students over **barrier concepts**
- Transition step between explanations and programs

Ada - the first dry runner?

- The claim that Ada Lovelace was the first programmer arises not because of a program listing she wrote
- She created a dry run table for Babbage's machine
- She pointed out a mistake in his algorithm as a result

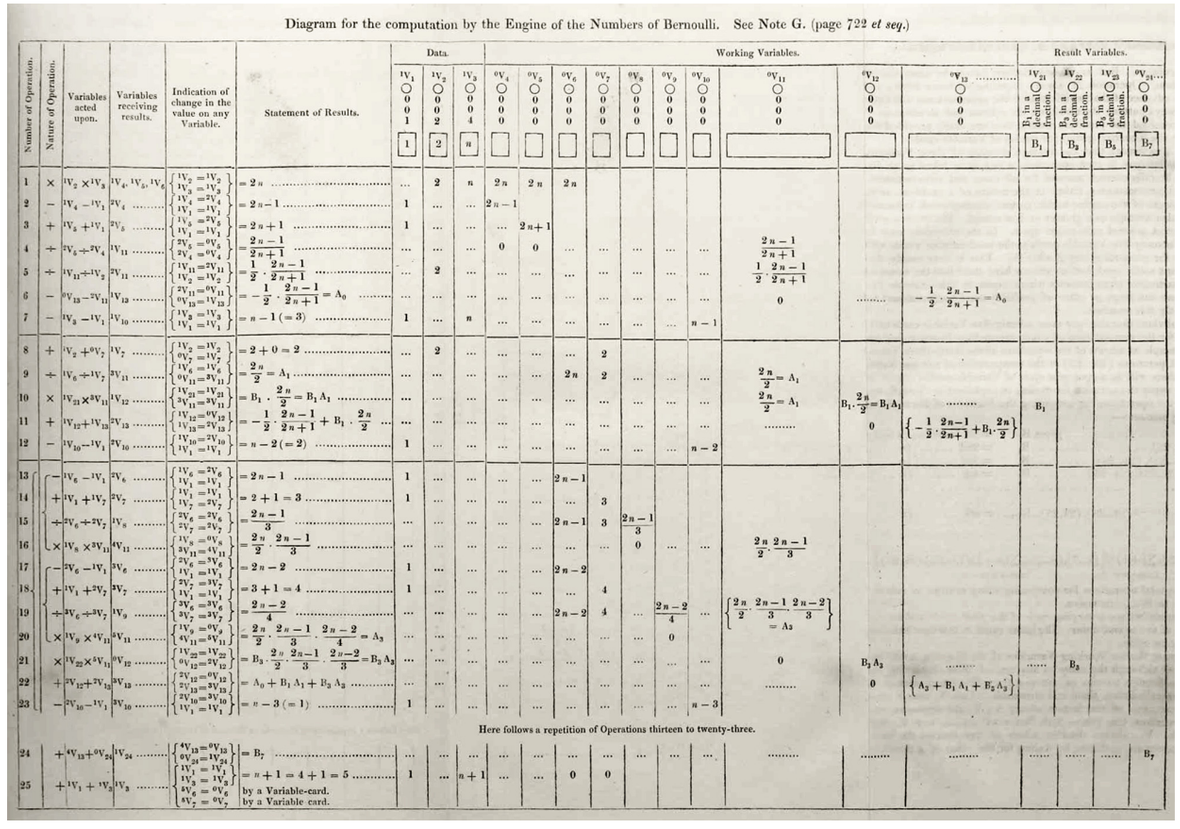


Diagram for the computation by the Engine of the Numbers of Bernoulli. See Note G. (page 722 *et seq.*)

Number of Operation.	Nature of Operation.	Variables acted upon.	Variables receiving results.	Indication of change in the value on any Variable.	Statement of Results.	Data. 1	Data. 2	Data. n	Working Variables.									Result Variables.			
						1	2	n										B_1	B_2	B_4	B_7
1	×	$^1V_2 \times ^1V_3$	$^1V_4, ^1V_5, ^1V_6$	$\left\{\begin{matrix}^1V_2 = {}^1V_2 \\ ^1V_3 = {}^1V_3\end{matrix}\right\}$	$= 2n$	...	2	n	$2n$	$2n$	$2n$									
2	−	$^1V_4 - {}^1V_1$	$^2V_4$	$\left\{\begin{matrix}^1V_4 = {}^2V_4 \\ ^1V_1 = {}^1V_1\end{matrix}\right\}$	$= 2n-1$	1	...	...	$2n-1$												
3	+	$^1V_5 + {}^1V_1$	$^2V_5$	$\left\{\begin{matrix}^1V_5 = {}^2V_5 \\ ^1V_1 = {}^1V_1\end{matrix}\right\}$	$= 2n+1$	1	...	...	...	$2n+1$										
4	÷	$^2V_5 \div {}^2V_4$	$^1V_{11}$	$\left\{\begin{matrix}^2V_5 = {}^0V_5 \\ ^2V_4 = {}^0V_4\end{matrix}\right\}$	$= \frac{2n-1}{2n+1}$	...	...	...	0	0	...	...	...	...	...	$\frac{2n-1}{2n+1}$					
5	÷	$^1V_{11} \div {}^1V_2$	$^2V_{11}$	$\left\{\begin{matrix}^1V_{11} = {}^2V_{11} \\ ^1V_2 = {}^1V_2\end{matrix}\right\}$	$= \frac{1}{2} \cdot \frac{2n-1}{2n+1}$	...	2	...	...	...	...	...	...	...	...	$\frac{1}{2} \cdot \frac{2n-1}{2n+1}$					
6	−	$^0V_{13} - {}^2V_{11}$	$^1V_{12}$	$\left\{\begin{matrix}^2V_{11} = {}^0V_{11} \\ ^0V_{13} = {}^1V_{13}\end{matrix}\right\}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$	...	...	...	...	...	...	...	...	...	...	0	.....	$-\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$			
7	−	$^1V_3 - {}^1V_1$	$^1V_{10}$	$\left\{\begin{matrix}^1V_3 = {}^1V_3 \\ ^1V_1 = {}^1V_1\end{matrix}\right\}$	$= n-1\ (=3)$	1	...	n	...	...	...	...	...	...	$n-1$						
8	+	$^1V_2 + {}^0V_2$	$^1V_7$	$\left\{\begin{matrix}^1V_2 = {}^1V_2 \\ ^0V_7 = {}^1V_7\end{matrix}\right\}$	$= 2+0 = 2$	...	2	...	...	...	...	2									
9	÷	$^1V_6 \div {}^1V_2$	$^2V_{11}$	$\left\{\begin{matrix}^1V_6 = {}^2V_6 \\ ^0V_{11} = {}^2V_{11}\end{matrix}\right\}$	$= \frac{2n}{2} = A_1$	...	...	...	...	...	$2n$	2	...	...	...	$\frac{2n}{2} = A_1$					
10	×	$^1V_{21} \times {}^2V_{11}$	$^1V_{12}$	$\left\{\begin{matrix}^1V_{21} = {}^0V_{21} \\ ^2V_{11} = {}^3V_{11}\end{matrix}\right\}$	$= B_1 \cdot \frac{2n}{2} = B_1 A_1$	...	...	...	...	...	...	...	...	...	...	$\frac{2n}{2} = A_1$	$B_1 \cdot \frac{2n}{2} = B_1 A_1$	.....	B_1		
11	+	$^1V_{12} + {}^1V_{13}$	$^2V_{13}$	$\left\{\begin{matrix}^1V_{12} = {}^0V_{12} \\ ^1V_{13} = {}^2V_{13}\end{matrix}\right\}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}$	...	...	...	...	...	...	...	...	...	...	.....	0	$\left\{-\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}\right\}$			
12	−	$^1V_{10} - {}^1V_1$	$^2V_{10}$	$\left\{\begin{matrix}^1V_{10} = {}^2V_{10} \\ ^1V_1 = {}^1V_1\end{matrix}\right\}$	$= n-2\ (=2)$	1	...	...	...	...	...	...	...	...	$n-2$						
13	−	$^1V_6 - {}^1V_1$	$^2V_6$	$\left\{\begin{matrix}^1V_6 = {}^2V_6 \\ ^1V_1 = {}^1V_1\end{matrix}\right\}$	$= 2n-1$	1	...	...	...	...	$2n-1$										
14	+	$^1V_1 + {}^2V_7$	$^2V_7$	$\left\{\begin{matrix}^1V_1 = {}^1V_1 \\ ^2V_7 = {}^2V_7\end{matrix}\right\}$	$= 2+1 = 3$	1	...	...	...	...	...	3									
15	÷	$^2V_6 \div {}^2V_7$	$^1V_8$	$\left\{\begin{matrix}^2V_6 = {}^2V_6 \\ ^2V_7 = {}^2V_7\end{matrix}\right\}$	$= \frac{2n-1}{3}$	...	...	...	...	...	$2n-1$	3	$\frac{2n-1}{3}$								
16	×	$^1V_8 \times {}^3V_{11}$	$^4V_{11}$	$\left\{\begin{matrix}^1V_8 = {}^0V_8 \\ ^3V_{11} = {}^4V_{11}\end{matrix}\right\}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3}$	...	...	...	...	...	...	...	0	...	...	$\frac{2n}{2} \cdot \frac{2n-1}{3}$					
17	−	$^2V_6 - {}^1V_1$	$^3V_6$	$\left\{\begin{matrix}^2V_6 = {}^3V_6 \\ ^1V_1 = {}^1V_1\end{matrix}\right\}$	$= 2n-2$	1	...	...	...	...	$2n-2$										
18	+	$^1V_1 + {}^2V_7$	$^3V_7$	$\left\{\begin{matrix}^2V_7 = {}^3V_7 \\ ^1V_1 = {}^1V_1\end{matrix}\right\}$	$= 3+1 = 4$	1	...	...	...	...	...	4									
19	÷	$^3V_6 \div {}^3V_7$	$^4V_9$	$\left\{\begin{matrix}^3V_6 = {}^3V_6 \\ ^3V_7 = {}^3V_7\end{matrix}\right\}$	$= \frac{2n-2}{4}$	...	...	...	...	...	$2n-2$	4	...	$\frac{2n-2}{4}$	...	$\left\{\frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{3}\right\} = A_2$					
20	×	$^1V_9 \times {}^4V_{11}$	$^5V_{11}$	$\left\{\begin{matrix}^1V_9 = {}^0V_9 \\ ^4V_{11} = {}^5V_{11}\end{matrix}\right\}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{4} = A_3$	...	...	...	...	...	...	...	...	...	0						
21	×	$^1V_{22} \times {}^5V_{11}$	$^6V_{12}$	$\left\{\begin{matrix}^1V_{22} = {}^1V_{22} \\ ^0V_{12} = {}^2V_{12}\end{matrix}\right\}$	$= B_3 \cdot \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{3} = B_3 A_3$	...	...	...	...	...	...	...	...	...	...	0	$B_3 A_3$	.....	.....	B_3	
22	+	$^2V_{12} + {}^2V_{13}$	$^3V_{13}$	$\left\{\begin{matrix}^2V_{12} = {}^0V_{12} \\ ^2V_{13} = {}^3V_{13}\end{matrix}\right\}$	$= A_0 + B_1 A_1 + B_3 A_3$	...	...	...	...	...	...	...	...	...	...	.....	0	$\{A_3 + B_1 A_1 + B_3 A_3\}$			
23	−	$^2V_{10} - {}^1V_1$	$^3V_{10}$	$\left\{\begin{matrix}^2V_{10} = {}^3V_{10} \\ ^1V_1 = {}^1V_1\end{matrix}\right\}$	$= n-3\ (=1)$	1	...	...	...	...	...	...	...	...	$n-3$						
Here follows a repetition of Operations thirteen to twenty-three.																					
24	+	$^4V_{13} + {}^0V_{24}$	$^1V_{24}$	$\left\{\begin{matrix}^4V_{13} = {}^0V_{13} \\ ^0V_{24} = {}^1V_{24}\end{matrix}\right\}$	$= B_7$	...	...	...	...	...	...	...	...	...	...	.....	.....	.....	.....	.....	B_7
25	+	$^1V_1 + {}^1V_3$	$^1V_3$	$\left\{\begin{matrix}^1V_1 = {}^1V_1 \\ ^1V_3 = {}^1V_3 \\ ^1V_6 = {}^0V_6 \\ ^1V_7 = {}^0V_7\end{matrix}\right\}$	$= n+1 = 4+1 = 5$ by a Variable-card. by a Variable card.	1	...	$n+1$	...	...	0	0									

Elf Computers

- Compile programs on to people
- Act out the computation step by step
- Why?
- GOOD WAY TO EXPLAIN SEMANTICS
- see work on ‘semantic waves’

Let’s explore an example unplugged role play dry run activity:

Box Variables

Exercise

- When I get to the role play…
- You should work through the example at home
    - Moving paper between boxes…
    - Or draw (a cartoon strip) of what happens
- COPYING THE ACTION!

We are going to explore what a variable is and how they work

You will be able to:

- explain what a variable is
- work out what simple programs that manipulate variables do, step by step

I’m going to use lego figures instead of people

- Variables are like storage boxes
- Special ones that can
  – Store
  – Create
  – Destroy

What does this (python) code do?

```
colour1 = “red”
colour2 = “green”

temp = colour1
colour1 = colour2
colour2 = temp
```

Let’s act it out (remember join in at home) !

See the Box Variables Video

teachinglondoncomputing.org/dryrun/

Exercise

In the google Doc…

http://bit.ly/CS4FN-DRYRUN

Write down as many facts about variables that we have just come across as you can

Main points

- A Variable is a storage space that holds data for later use in a program
- Variables have names
  - so the computer knows which one is meant.
- Variables hold values
  - the actual data that is being stored.
- Do not confuse variable names with their values!

- A variable can only store one value at a time.
- When accessing a variable's value you make a copy
  - that variable's value is untouched.
- When you store a value in a variable you destroy anything that was previously there.

Towards Dry Run Tables
What does this program do?

Draw a series of pictures of boxes to find out…

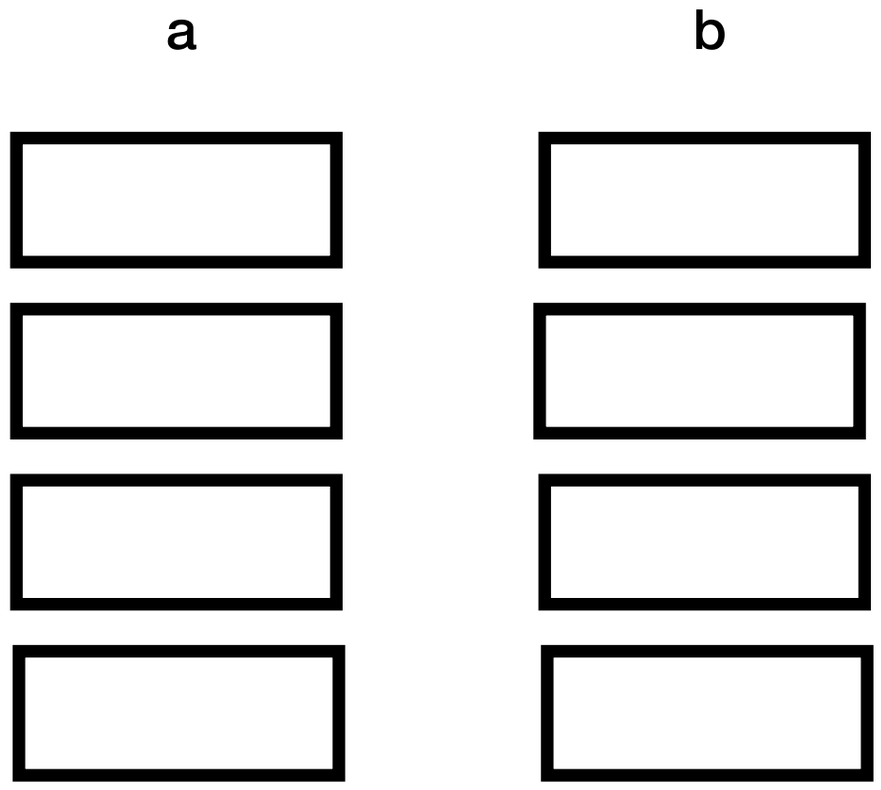
Draw the new state of the boxes with each line

a = 1

b = 2

b = a

a = b



Dry Run tables

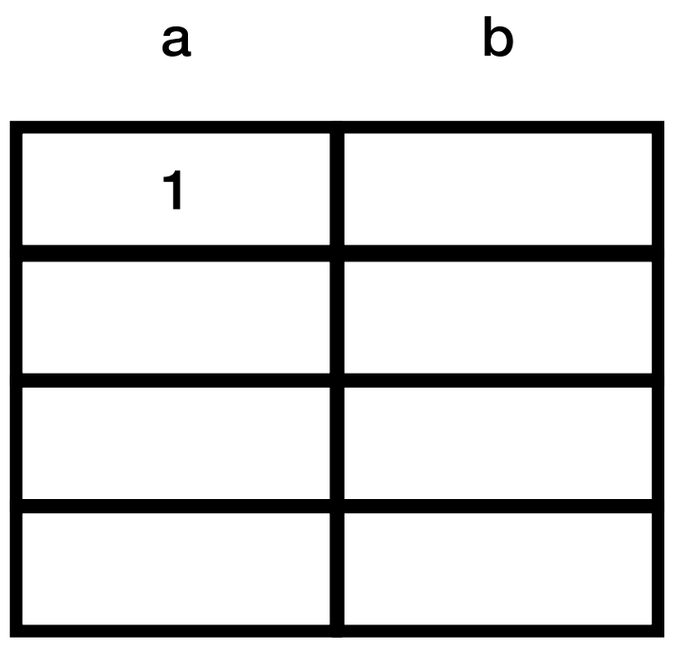
- This leads directly to the idea of dry run tables
- Combine the boxes into a table

a = 1

b = 2

b = a

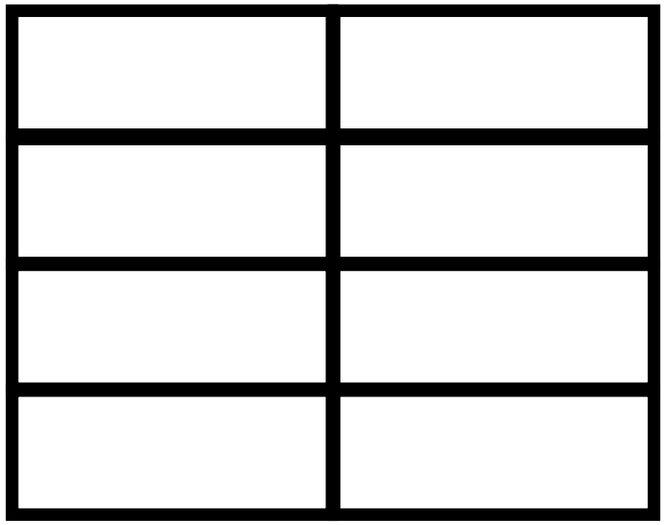
a = b



Dry Run Tables: Example

- Let's draw a table to see what this does:

a = 1
b = 2
b = a
a = b



Dry Run Tables: Example

```
a = 1
b = 2
b = a
a = b
```

a
1

Dry Run Tables: Example

a = 1

b = 2

b = a

a = b

a	b
1	
	2

Dry Run Tables: Example

a = 1

b = 2

b = a

a = b

a	b
1	
	~~2~~
	1

Dry Run Tables: Example

a = 1

b = 2

b = a

a = b

a	b
~~1~~	
	~~2~~
	1
1	

Exercise: Your turn

- What does this code do?
- Fill in this dry run table…

colour1 = “red”
colour2 = “green”
colour1 = colour2
colour2 = colour1

colour1	colour2

Solution

colour1 = “red”

colour2 = “green”

colour1 = colour2

colour2 = colour1

colour1	colour2
~~“red”~~	
	~~“green”~~
“green”	
	“green”

Diagnostic Tests

- A powerful way to detect (and correct) misconceptions early
- Set weekly dry run tests of (eg 5-12) short, critical dry runs
- Require table solutions
- Mark immediately
- Fix the mental models of those making mistakes (immediately)

Show all your working in the following. Justify your answers!

1. What are the new values of a and b after the following code fragment has executed?

```
int  a = 10;
int  b = 20;
a = b;
```

a is now _____ **b is now _____**

2. What are the new values of a and b after the following code fragment has executed?

```
int  a = 10;
int  b = 20;
b = a;
```

a is now _____ **b is now _____**

3. What are the new values of big and small after the following code fragment has executed?

```
int  big  =  10;
int  small = 20;
big = small;
```

big is now _____ **small is now _____**

Exercise

Now you do the diagnostic test…
No marks if you do not fill out the tables!

You can download it from:

http://bit.ly/CS4FN-DRYRUN

Fix the problems

- Immediately sit down with anyone who got most wrong
- Do the first one in front of them
  - (you may see the lightbulb appear above their head)
  - Get them to do one while you watch
  - Leave them to do the rest again
- Odd ones wrong - point out attention to detail matters.
- None wrong - praise their attention to detail

Dry Run tables are important

- Drawing tables matters (educationally)
  - Do NOT let students do it in their head.
  - Once you can program doing this is rare
- BUT **pedagogically** it is a critical activity
- Programmers reason at a higher level of abstraction most of the time
  - writing tables gives a foundation for that

If statements, loops etc

- The ideas extend to loops and if statements
- When dry running:
  - **add an extra column for any test**

- Compile programs on to ‘Imp Computers’
  - people represent instructions,
  - linked together by rope to represent the control structure

If statements, loops etc

- Add a column for each test
- Add new rows for each time round a loop

```
a = 2
if a==3:
    b = 5
else
    b = 7
```

a	b	a==3?
2		
		2==3? false
	7	

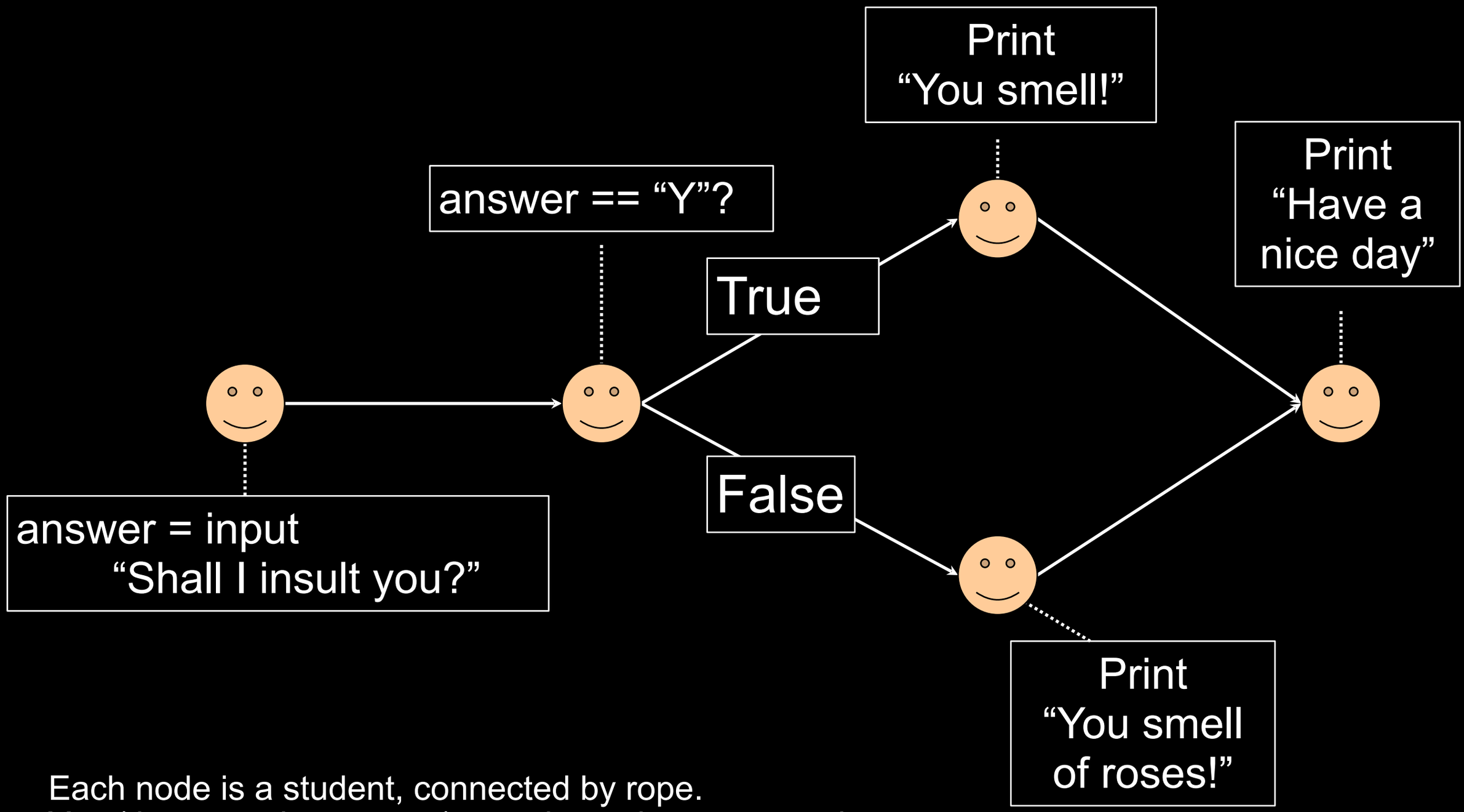
An Insulting Program

```
answer = input (“Shall I insult you?”)

if answer == “Y”:
        print (“You smell!”)
else:
        print (“You smell of roses!”)

print (“Have a nice day”)
```

What it compiles to …



Each node is a student, connected by rope.
You (the operating system) pass in a tube at one end.
When it is handed back something should be printed on the screen (written on the board)

Explaining programming concepts

- We've made an invisible program tangible
- Can now explain all sorts of concepts
  - If statements
  - Control structures
  - The program counter
  - Run-time versus compile time
- Similar approach for loops

More advanced concepts

- Can also explore more advanced ideas
  - How program changes change structure
  - Optimizing compilers
  - Bugs

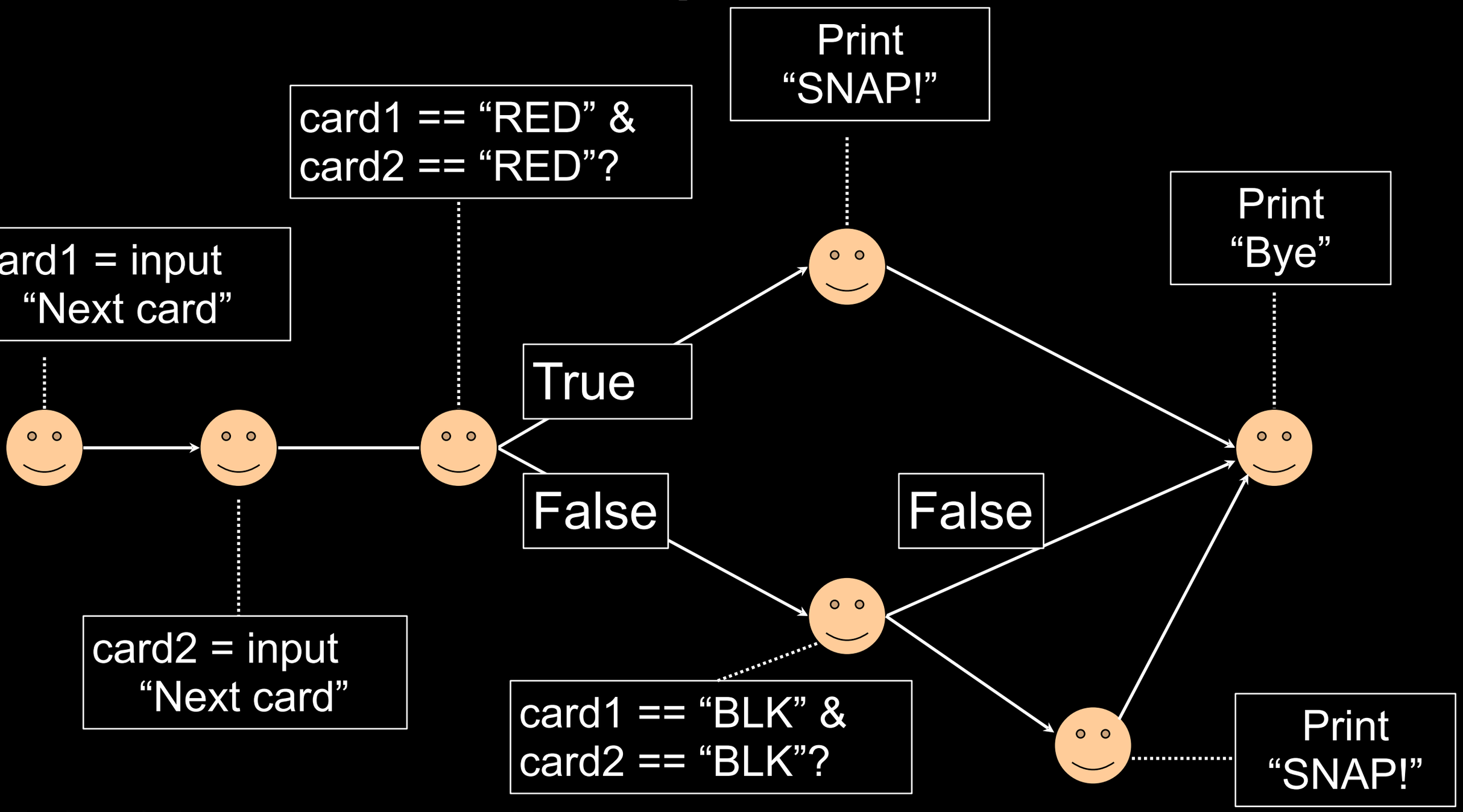
A Snap Program

```
card1 = input (“Next card”)
card2 = input (“Next card”)

if card1 == “RED” and card2 == “RED”:
        print (“SNAP!”)
else:
        if card1 == “BLACK” and card2 == “BLACK”:
                print (“SNAP!”)

print (“Bye”)
```

What it compiles to …

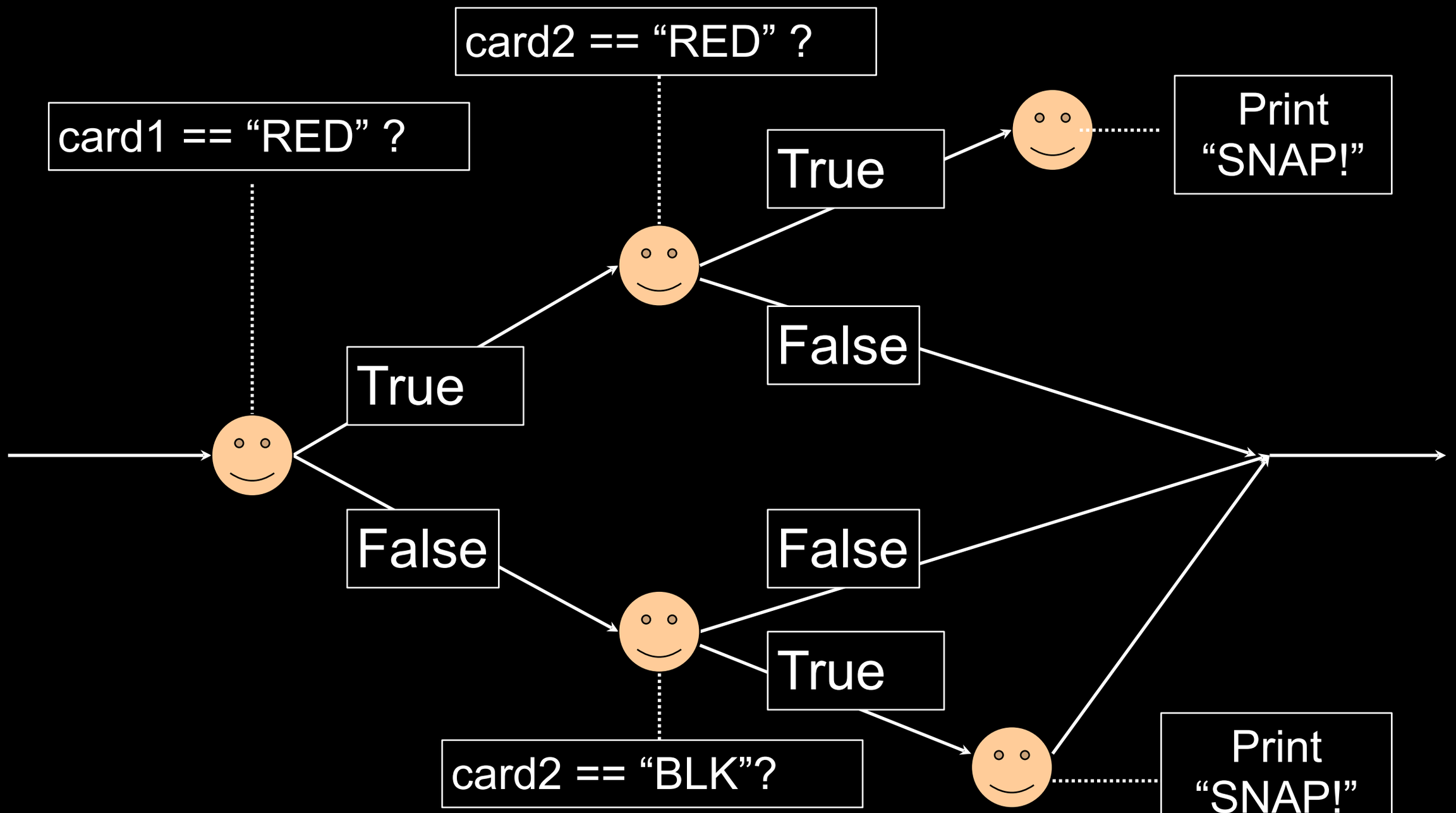


Each node is a student, connected by rope.
You (the operating system) pass in a tube at one end.
When it is handed back something should be printed on the screen (written on the board)

Exploring Different Programs

```
if card1 == “RED”:
    if card2 == “RED”:
        print (“SNAP!”)
else:
    if card2 == BLACK:
        print (“SNAP!”)
```

What it compiles to …



Each node is a student, connected by rope.
You (the operating system) pass in a tube at one end.
When it is handed back something should be printed on the screen (written on the board)

Summary

- It is understanding semantics that matters when learning to program
- Unplugged Role play (‘Imp computers’) is a powerful first step
- Making students draw dry run tables is the next vital learning activity

Why are these activities vital?

- Help in understanding **what constructs do** not just rote learning how to write them
- Develops **logical thinking**
- Develops **attention to detail**
- Allows teacher to quickly **identify misconceptions** and faulty mental models
- Helps students over **barrier concepts**
- **Transition** step between explanations and programs

Thank You

Please give feedback in the google doc

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teachinglondoncomputing.org/dryrun/

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EPSRC Engineering and Physical Sciences Research Council