

What computers just *cannot* do. (Part II)

COS 116, Spring 2012
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Recap from last time

... 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 ...

- Turing-Post computational model:
 - Greatly simplified model
 - Infinite tape, each cell contains symbol (0 or 1)
 - Program = finite sequence of instructions (only 6 types!)
 - Unlike pseudocode, no conditionals or loops, only “GOTO”
 - $\text{code}(P)$ = binary representation of program P

Example: doubling program

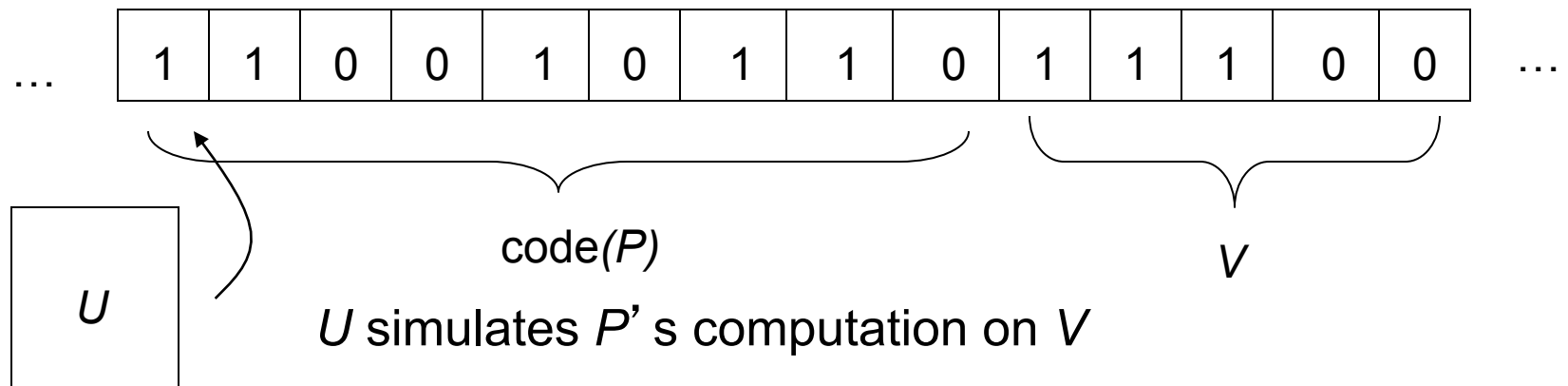
... 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 ...

1. PRINT 0
2. GO LEFT
3. GO TO STEP 2 IF 1 SCANNED
4. PRINT 1
5. GO RIGHT
6. GO TO STEP 5 IF 1 SCANNED
7. PRINT 1
8. GO RIGHT
9. GO TO STEP 1 IF 1 SCANNED
10. STOP

Program **halts** on this input data if STOP is executed in a finite number of steps

Some facts

- Fact 1: Every pseudocode program can be written as a T-P program, and vice versa
- Fact 2: There exists a universal T-P program





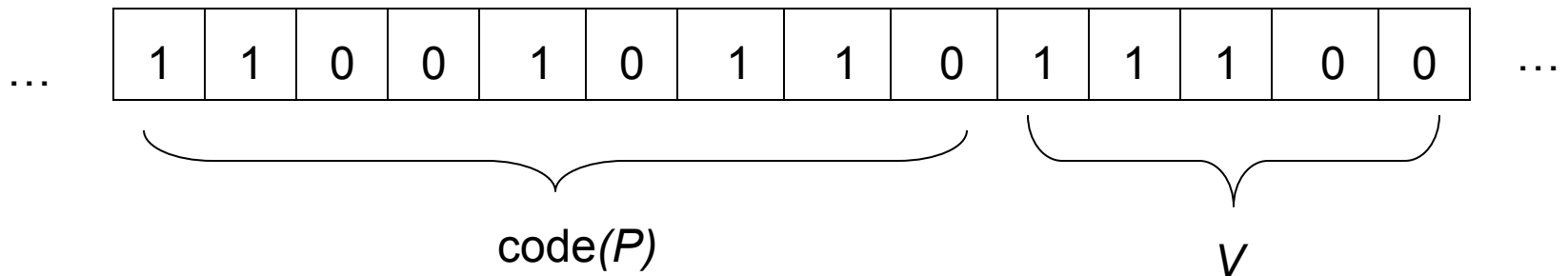
Discussion Time

Is there a universal pseudocode program ?

How would you write it?

What are some examples of universal programs in real life?

Halting Problem



- Decide whether P halts on V or not
- **Cannot be solved!** Turing proved that *no Turing-Post program can solve Halting Problem for all inputs ($code(P)$, V).*



Makes precise something quite intuitive:
“Impossible to demonstrate a negative”

Suppose program P halts on input V .
How can we detect this in finite time?

Proposal: “Just simulate.”

Intuitive difficulty: If P does not actually halt, no obvious way to detect this after just a finite amount of time.

Turing’s proof makes this intuition concrete.



Ingredients of the proof.....

Ingredient 1: “Proof by contradiction”

Fundamental assumption:
A mathematical statement is either
true or false

“When something’ s not right, it’ s wrong.”

Bob Dylan

Aside: Epimenides Paradox

- *Κρήτες ἀεί ψεύσται*
- “Cretans, always liars!”
- But Epimenides was a Cretan!

- More troubling: “This sentence is false.”



Ingredient 2:

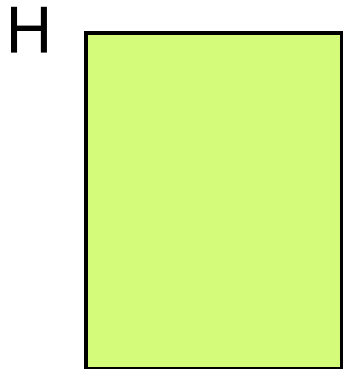


Suppose you have programs A and B.
What is the program whose net effect is
“Run A first and then B?”

Suppose you are given some T-P program P
How would you turn P into a T-P program
that does NOT halt on all inputs that P halts on?

Finally, the proof...

Suppose program H solves Halting Problem on ALL inputs of the form $\text{code}(P), V$.



Consider program D

1. On input V , check if it is code of a T-P program.
2. If no, HALT immediately.
3. If yes, use doubling program to create the bit string V, V and simulate H on it.
4. If H says “Doesn’t Halt”, HALT immediately.
5. If H says “Halts”, go into infinite loop

Gotcha! Does D halt on the input $\text{code}(D)$?

Either it halts or not – and both ways lead to contradictions!

Lessons to take away

- Computation is a very simple process (can arise in unexpected places)
- Universal Program
- No real boundary between hardware, software, and data
- No program that decides whether or not mathematical statements are theorems.
- Many tasks are uncomputable; e.g. “If we start Game of life in this configuration, will cell (100, 100) ever have a critter?”

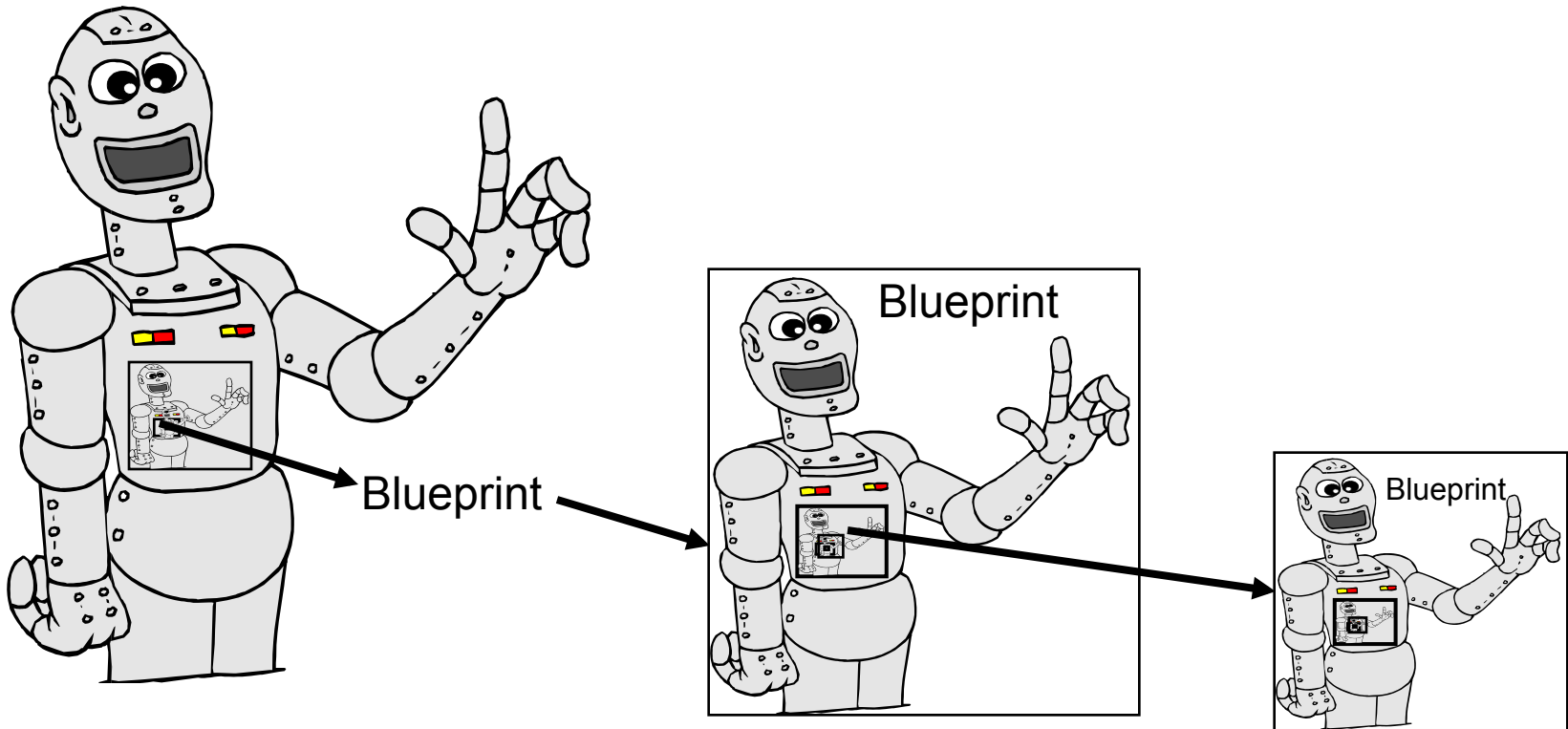
Age-old mystery: Self-reproduction.



How does the seed
encode the whole?

Self-Reproduction


False argument for impossibility:





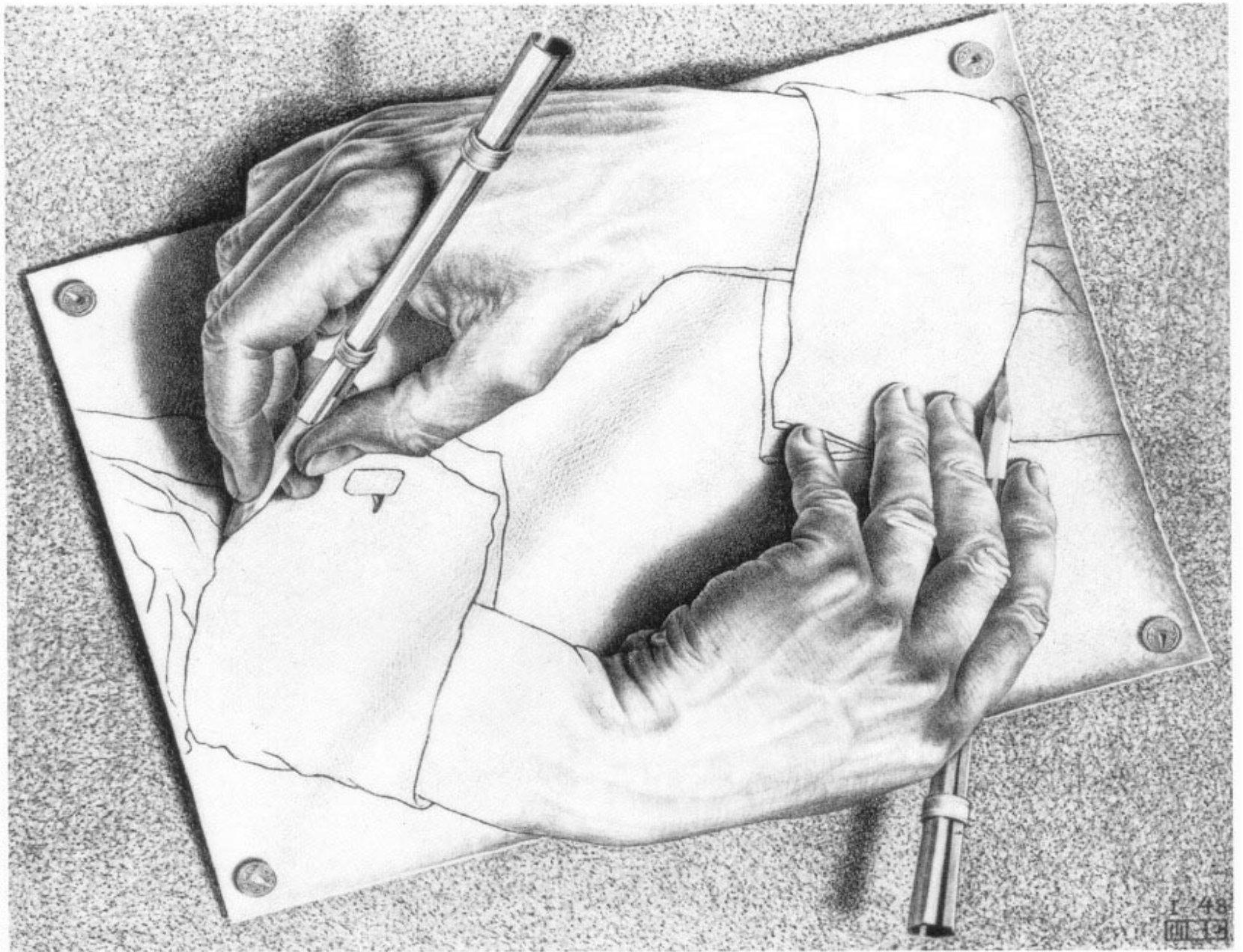
M.C. Escher

Print Gallery

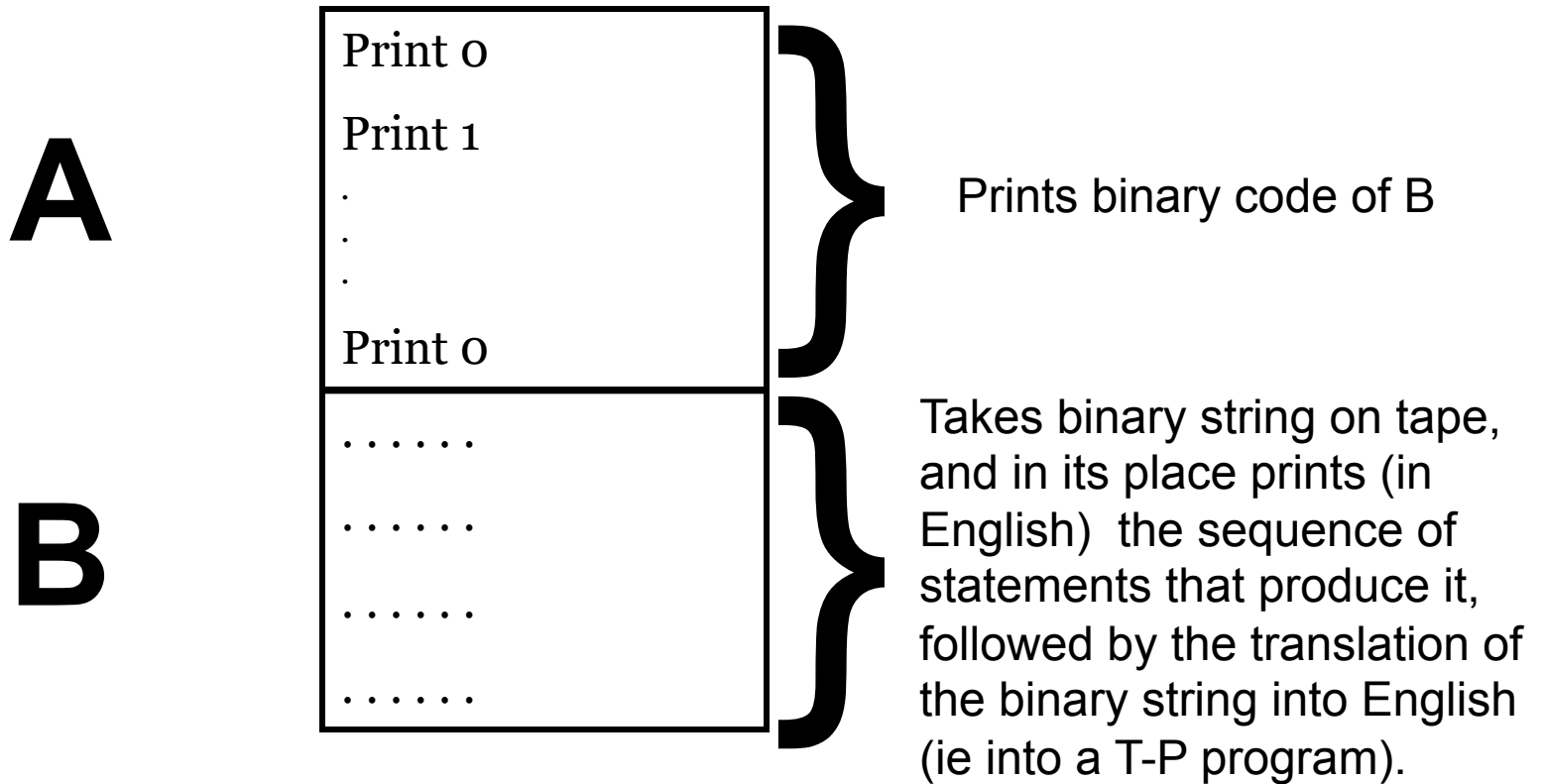


Fallacy Resolved: “Blueprint” can involve some computation; need not be an exact copy!

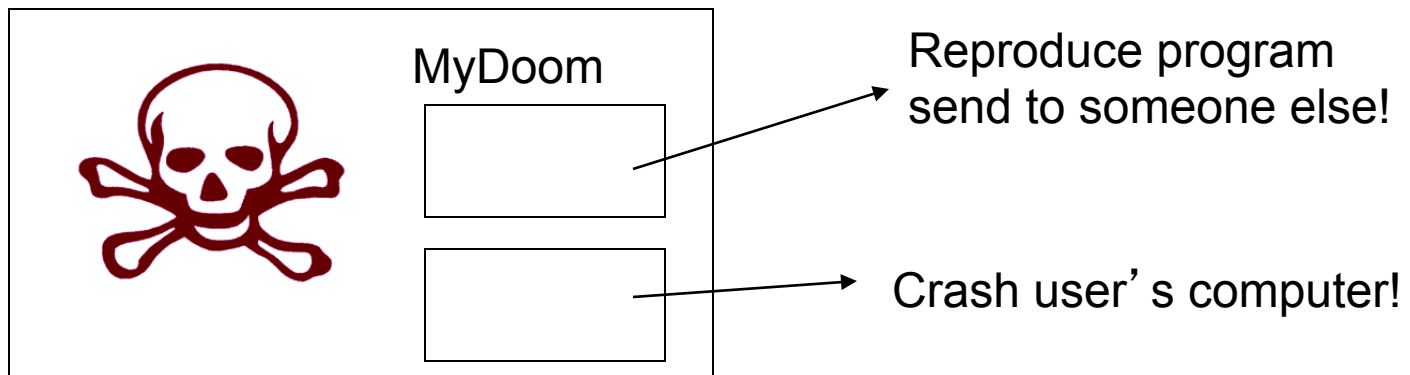
Print this sentence twice, the second time in quotes. “Print this sentence twice, the second time in quotes.”



High-level description of program that self-reproduces



Self-reproducing programs



- Fact: for every program P , there exists a program P' that has the exact same functionality except at the end it also prints $\text{code}(P')$ on the tape