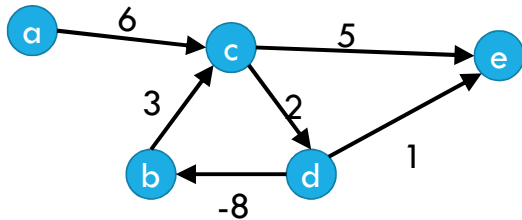


## Negative Edges

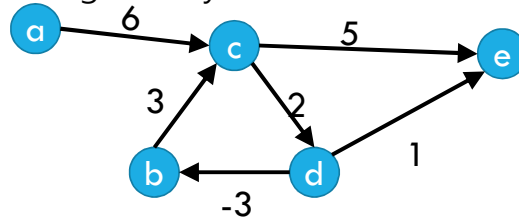
Negative Cycles



The fastest way from  $a$  to  $e$   
(i.e. least-weight walk) isn't  
defined!

No valid answer ( $-\infty$ )

Negative edges, but only non-  
negative cycles



Dijkstra's might fail

But the shortest path IS defined.

There is an answer

## Laundry List of shortest pairs (so far)

Algorithm	Running Time	Special Case only	Negative edges?
BFS	$O(m + n)$	ONLY unweighted graphs	X
Simple DP	$O(m + n)$	ONLY for DAGs	X
Dijkstra's	$O(m + n \log n)$		X
Bellman-Ford	$O(mn)$		Yes!

## A Linear Program

A linear program is defined by:

Real-valued **variables**

Subject to satisfying **everything** in a list of **linear constraints**

A linear constraint is a statement of the form:  $\sum a_i x_i \leq c_i$   
where  $a_i$  are constants, the  $x_i$  are variables and  $c_i$  is a constant.

Maximizing or minimizing a linear objective function

A linear objective function is a function of the form:  $\sum b_i x_i$   
where  $b_i$  are constants and the  $x_i$  are variables.

## Linear constraints

[Pollev.com/robbie](https://pollev.com/robbie)

Can you write each of these requirements as linear constraint(s)?

Some of these are tricks...

$x_i$  times  $x_j$  is at least 5

$5x_i$  is equal to 1

$x_i \leq 5$  OR  $x_i \geq 7$

$x_i$  is non-negative.

$x_i$  is an integer.