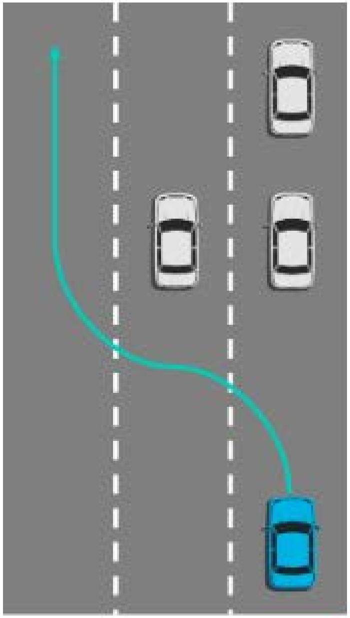
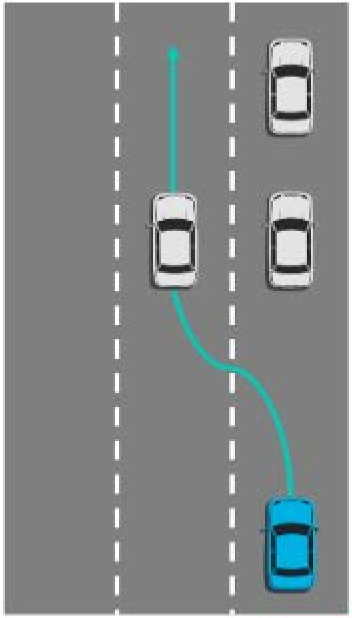
QUIZ QUESTION

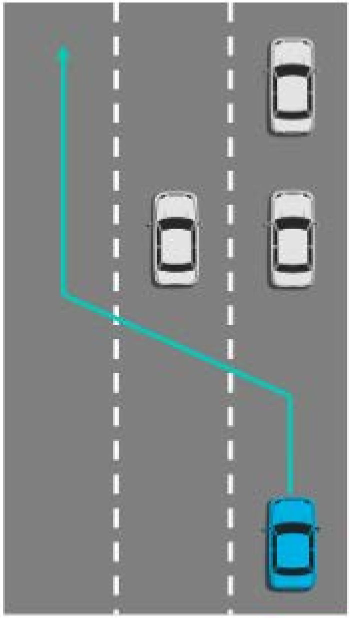
This is another milestone, to design how the car should move! In the picture below, which is the best trajectory for the green car here?



A



B



C

- ✓ A
- B
- C

Routing

SEND FEEDBACK

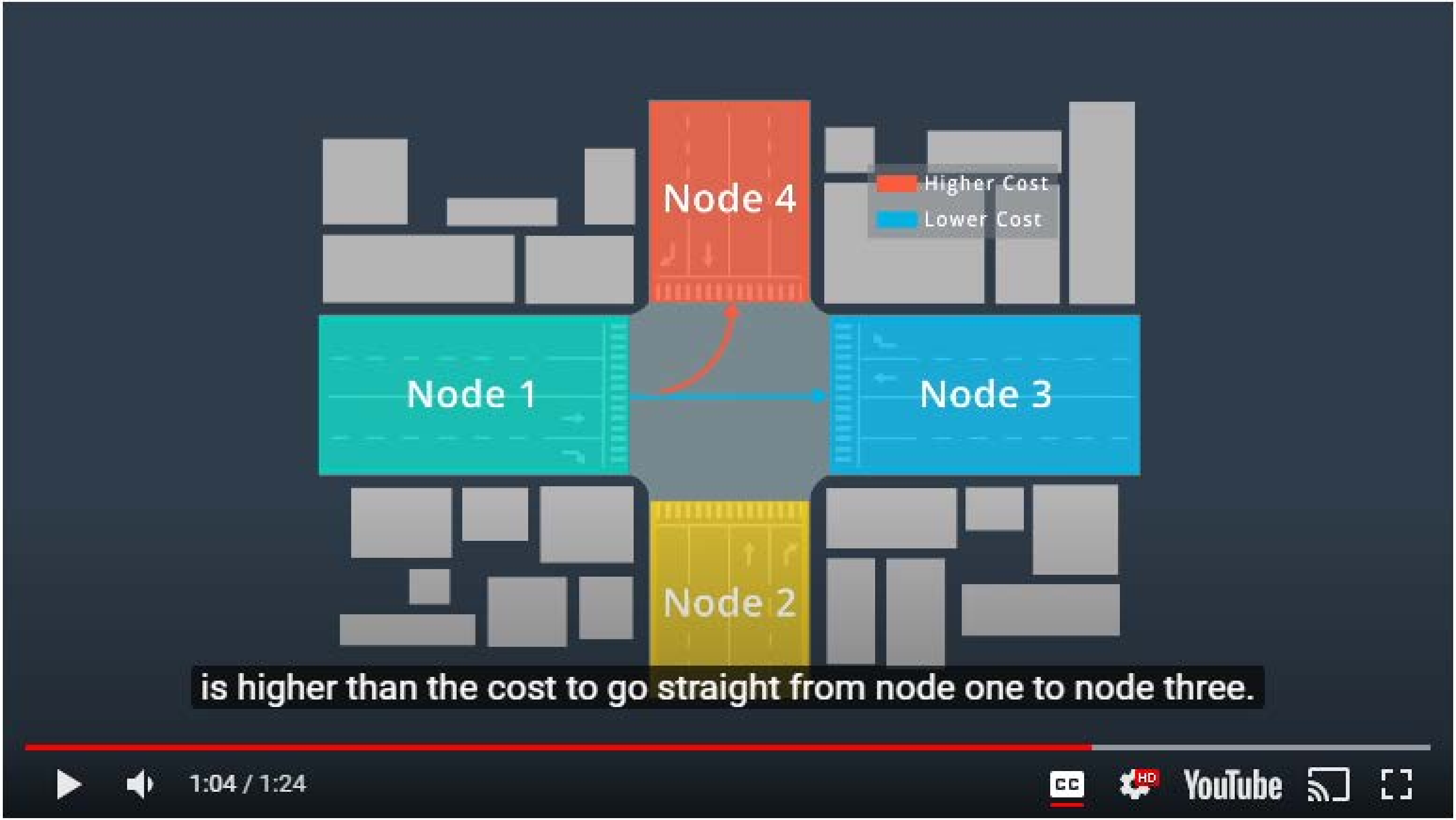

Routing takes three inputs, first the map.
0:10 / 0:36
YouTube


Second, our current position on the map.
0:19 / 0:36
YouTube

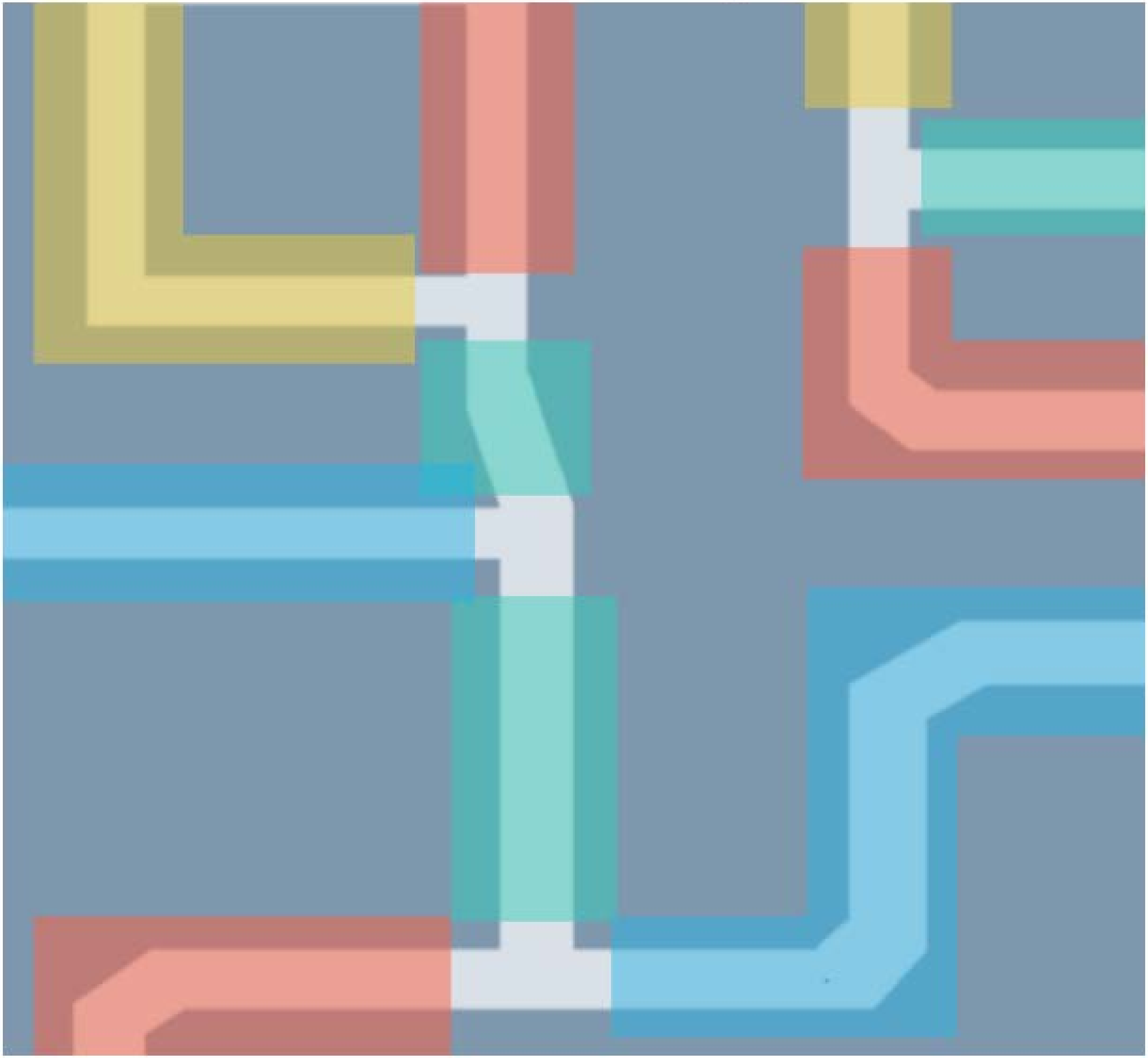

Third, our destination.
0:24 / 0:36
CC
HD
YouTube


it reformats the map into a data structure called a graph.
0:24 / 1:24
HD
YouTube


The graph consists of nodes and edges.
0:27 / 1:24
HD
YouTube

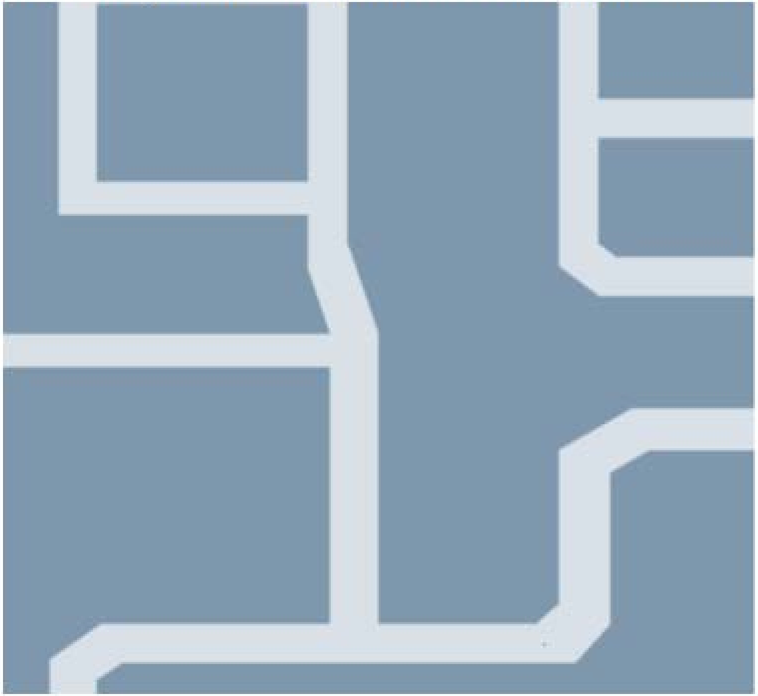

Node 4
Higher Cost
Lower Cost
Node 1
Node 3
Node 2
is higher than the cost to go straight from node one to node three.
1:04 / 1:24
YouTube

This is how we divide the region:



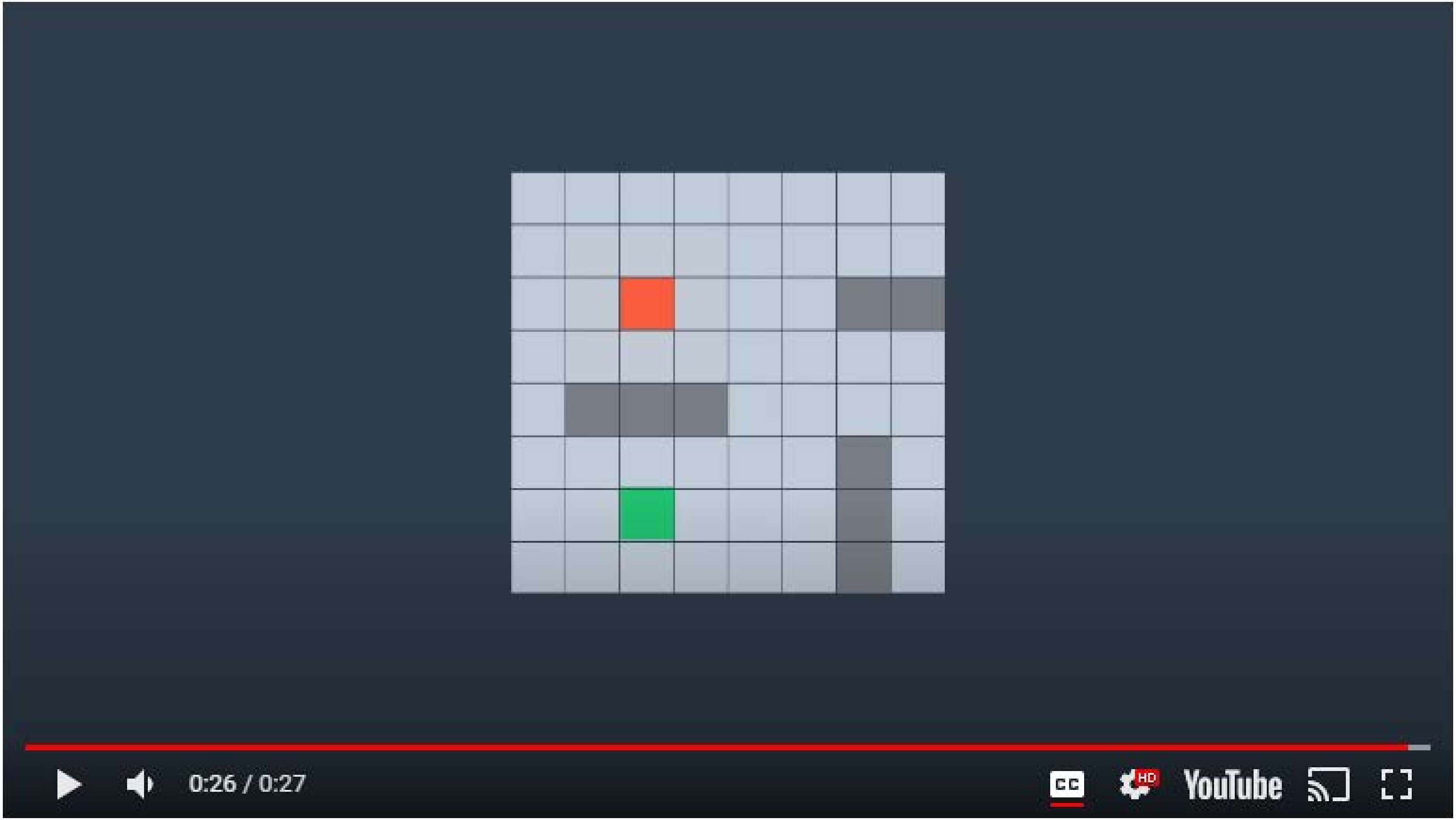
Nodes

How many nodes do we need to model the following region?

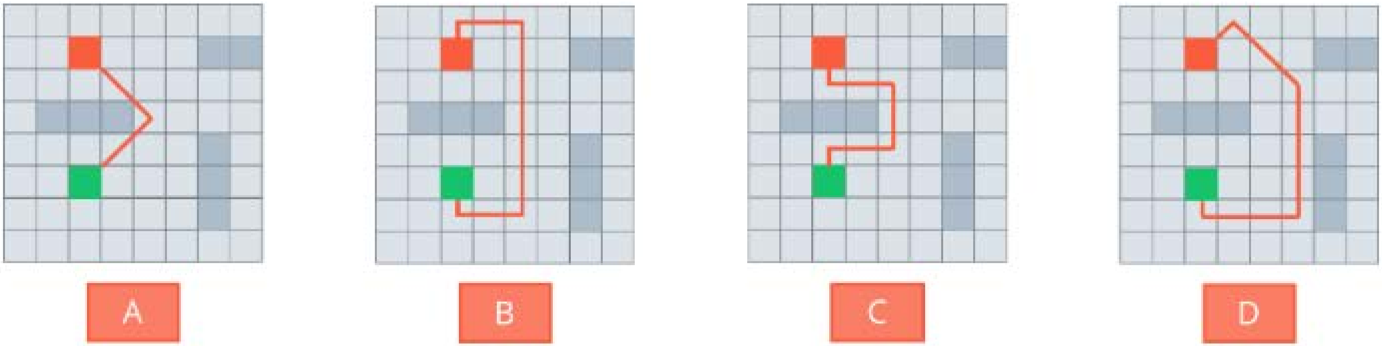


10

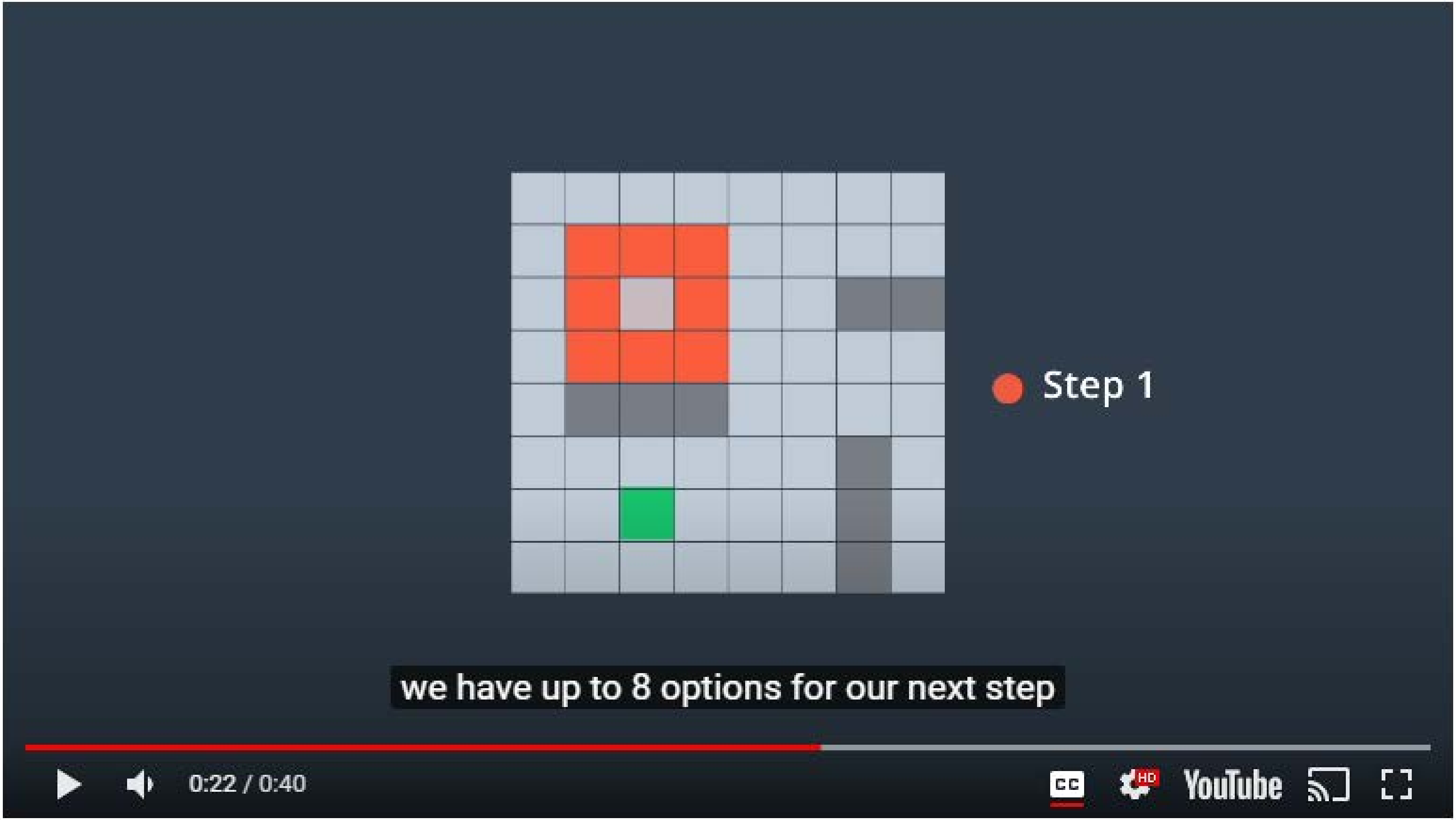
RESET

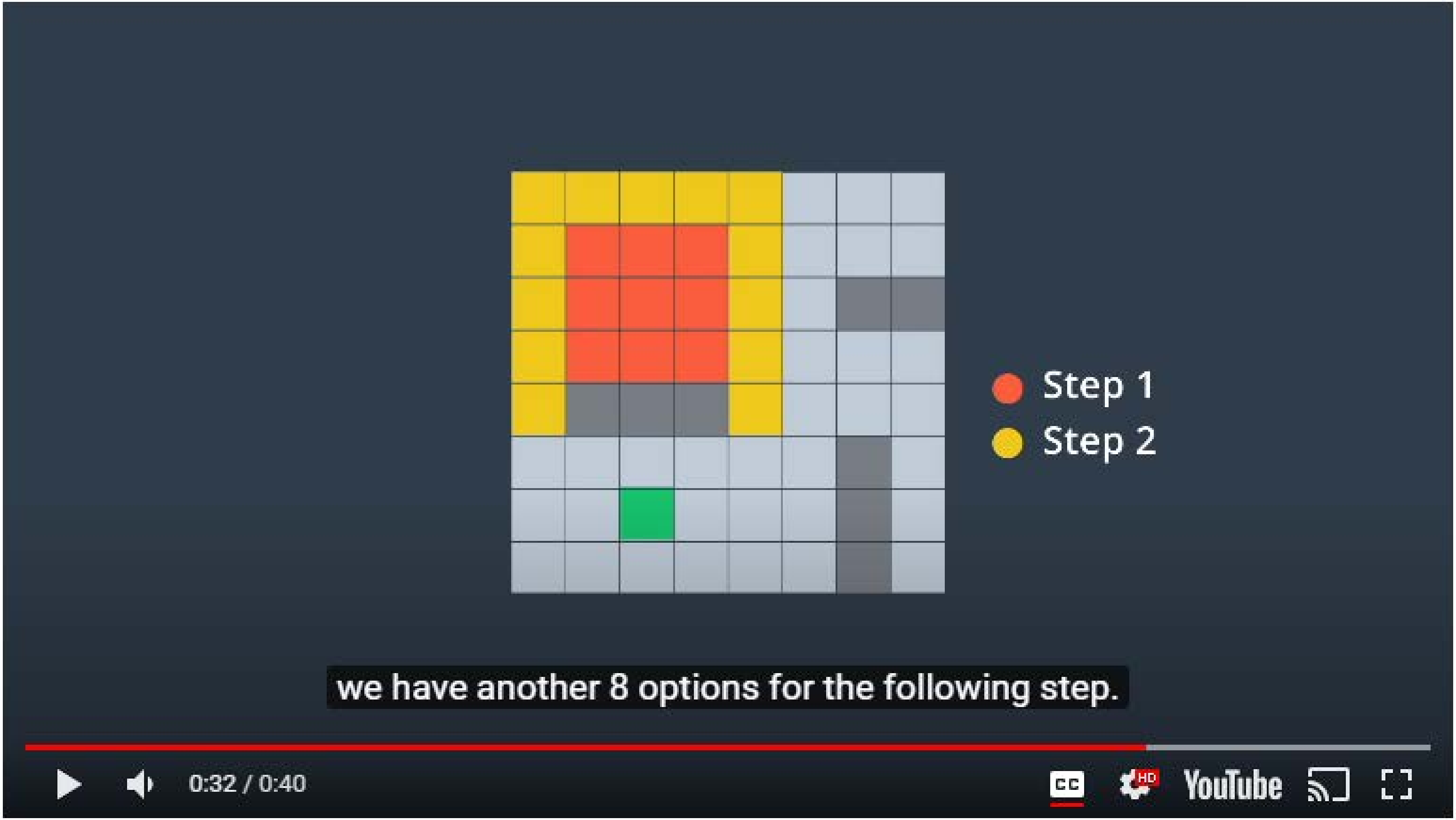

0:26 / 0:27
HD
YouTube

Let's test your intuition here! Suppose we're allowed to move left, right, up and down, and we're also allowed to move to the diagonal cells. Which of the following paths in the following picture will you take to move efficiently from the red cell to the green cell? Check all that apply.



- [x] A
- [ ] B
- [x] C
- [ ] D

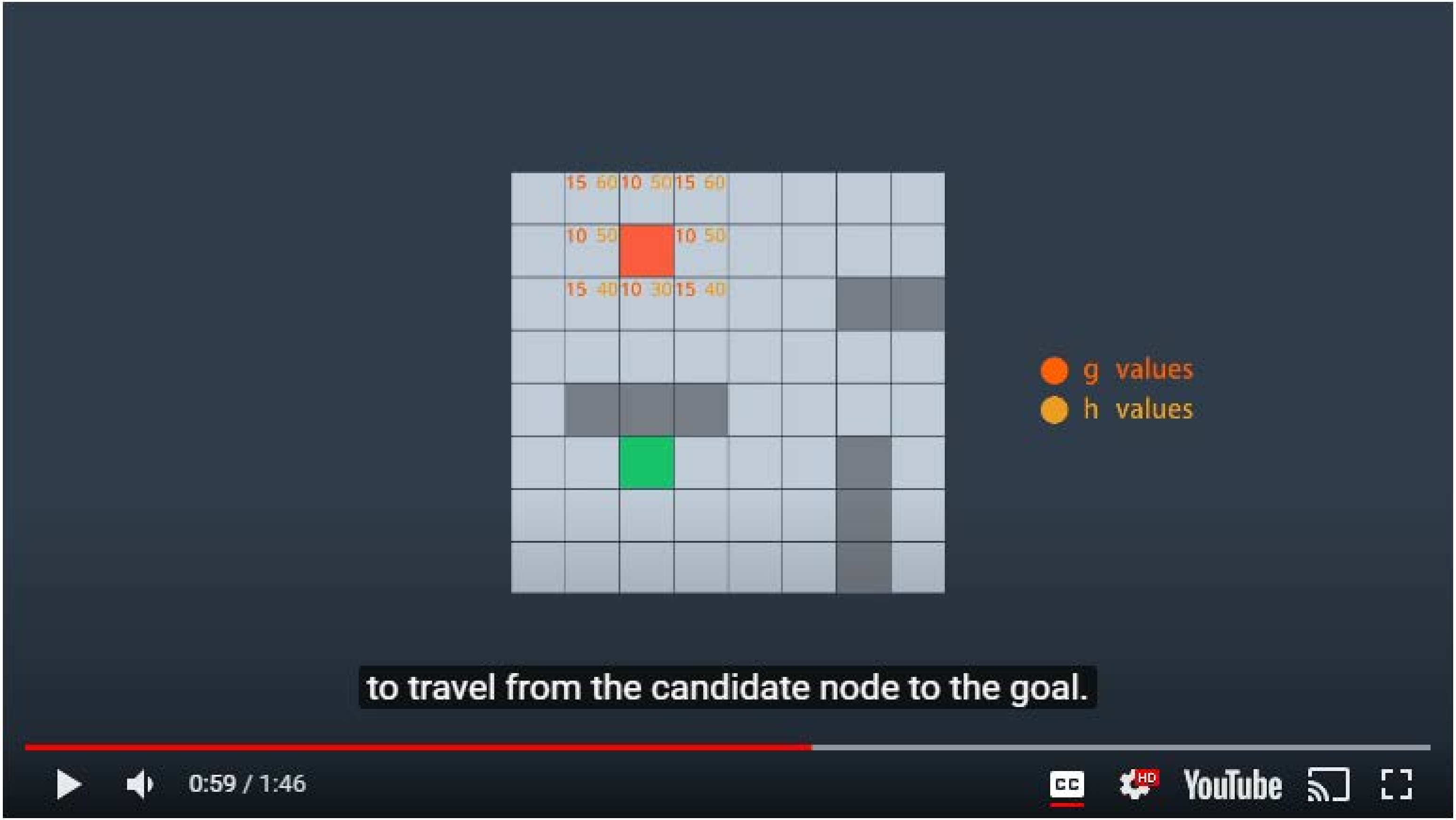

Step 1
we have up to 8 options for our next step
0:22 / 0:40

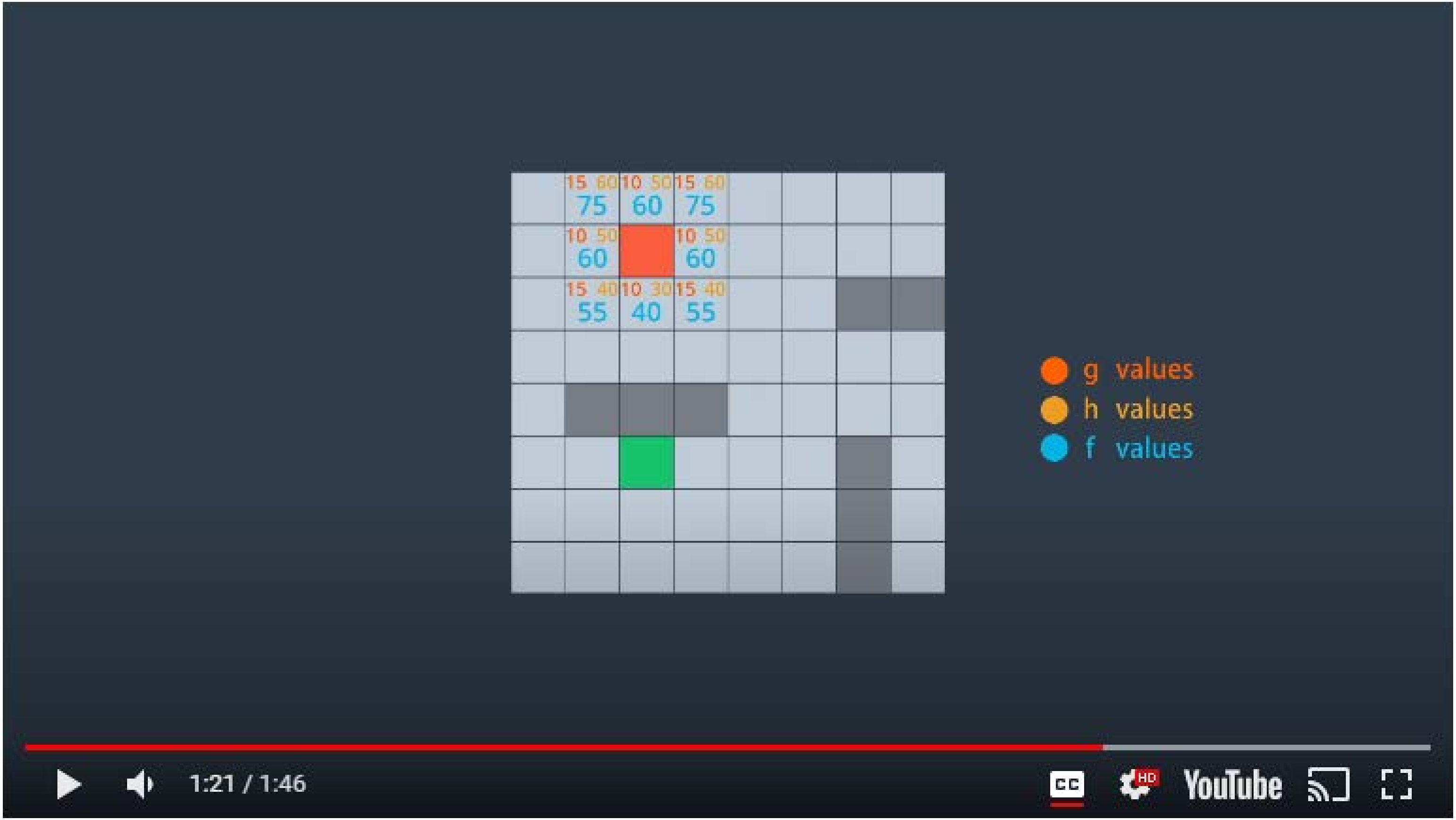

Step 1
Step 2
we have another 8 options for the following step.
0:32 / 0:40
HD
YouTube

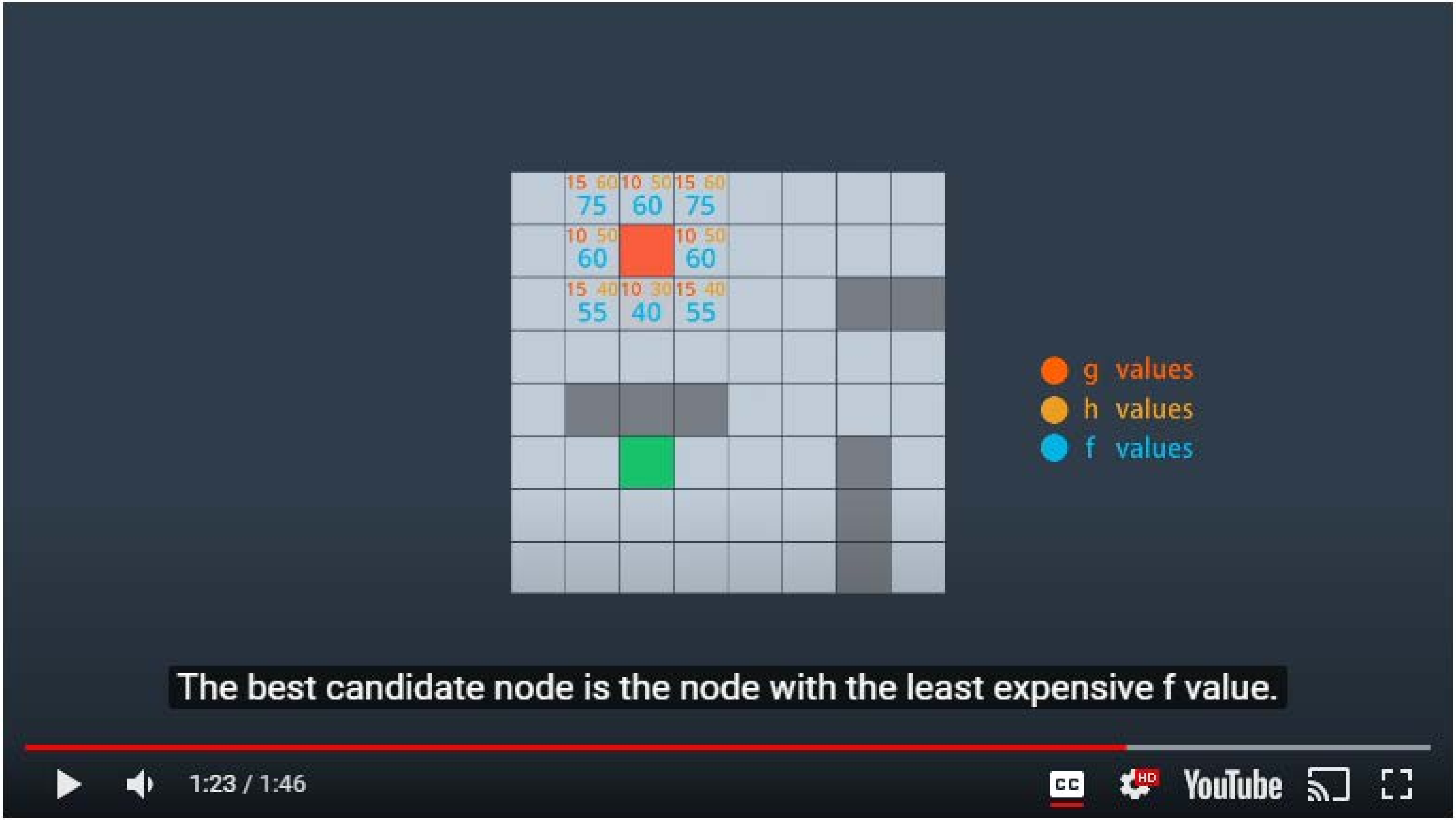
QUESTION 2 OF 4

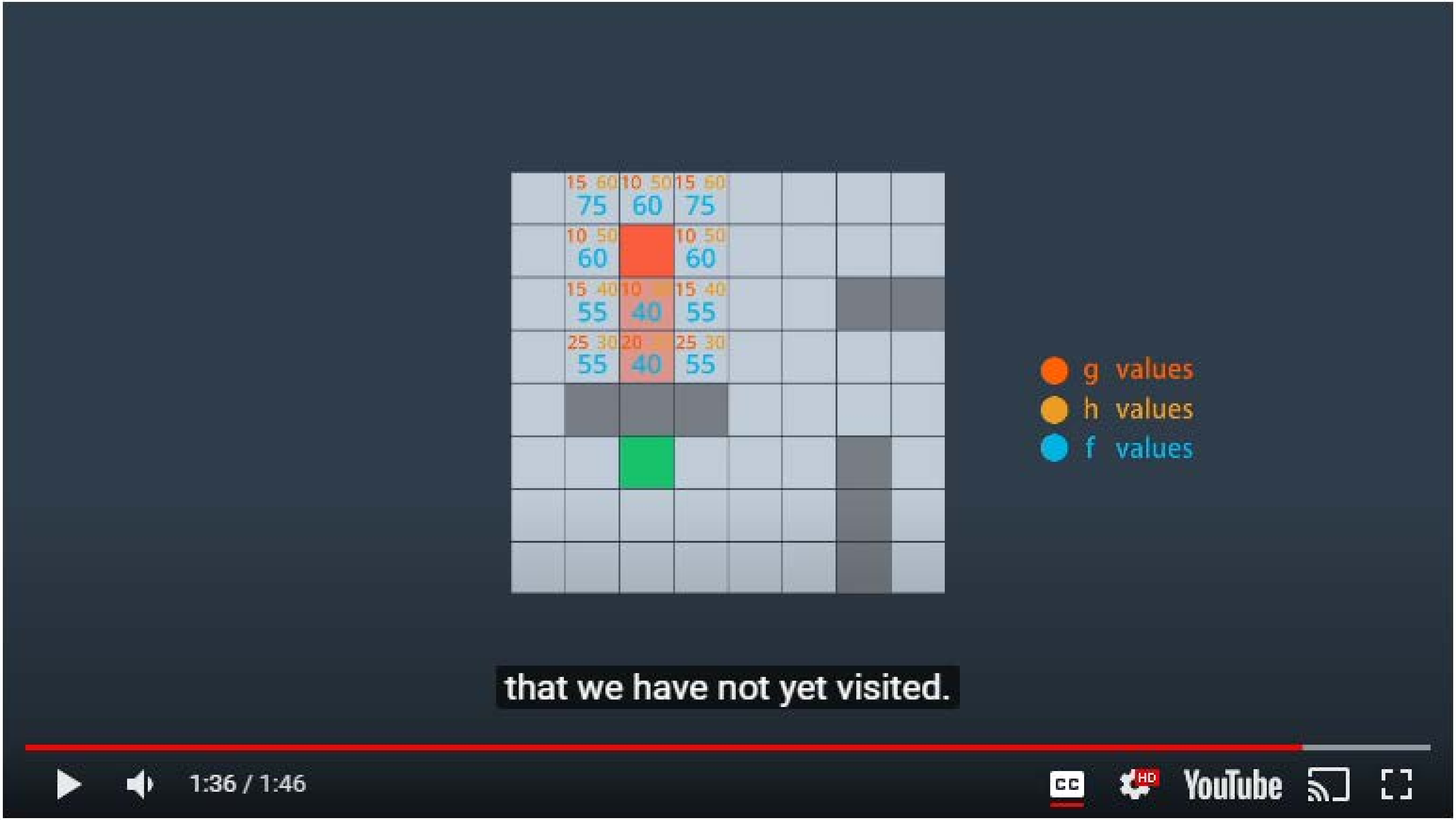
Which of the following method can help us narrow down the options we have for each step?

- [x] Never go back to grids we come from
- [ ] Go in one direction until we hit a wall
- [x] Try to take a step that's easier.
- [x] Choose the cell that is closer to our goal

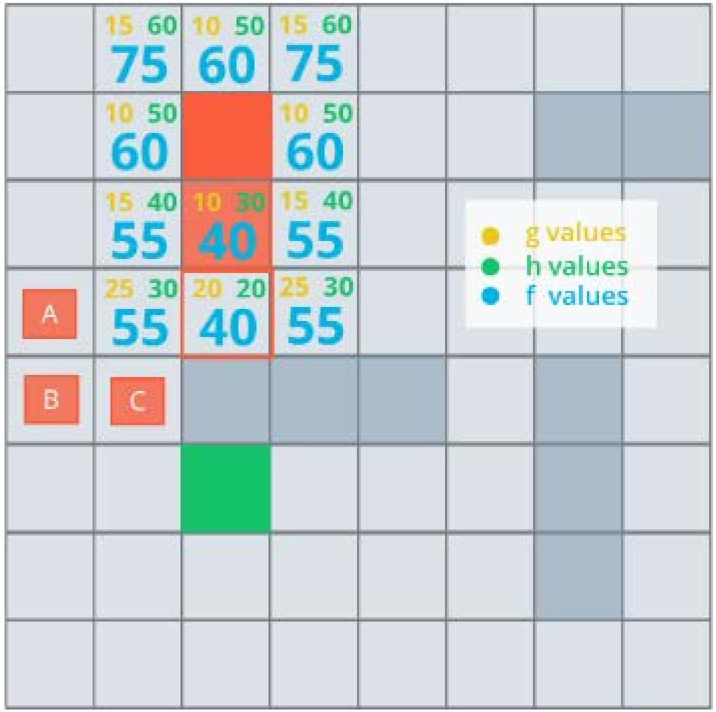

15 60
10 50
15 60
10 50
10 50
15 40
10 30
15 40
g values
h values
to travel from the candidate node to the goal.
0:59 / 1:46
HD
YouTube


15 60
75
10 50
60
15 60
75
10 50
60
10 50
60
15 40
55
10 30
40
15 40
55
g values
h values
f values
1:21 / 1:46
HD
YouTube


15 60
75
10 50
60
15 60
75
10 50
60
10 50
60
15 40
55
10 30
40
15 40
55
g values
h values
f values
The best candidate node is the node with the least expensive f value.
1:23 / 1:46


15 60
75
10 50
60
15 60
75
10 50
60
10 50
60
15 40
55
10
40
15 40
55
25 30
55
20
40
25 30
55
g values
h values
f values
that we have not yet visited.
1:36 / 1:46
YouTube

In the picture below, Which cells will be evaluated for the first time in the next step?



- A
- B
- C

Question 2

In the above picture, what are the g value, h value and f value for this cell? (separated by comma)

Your reflection

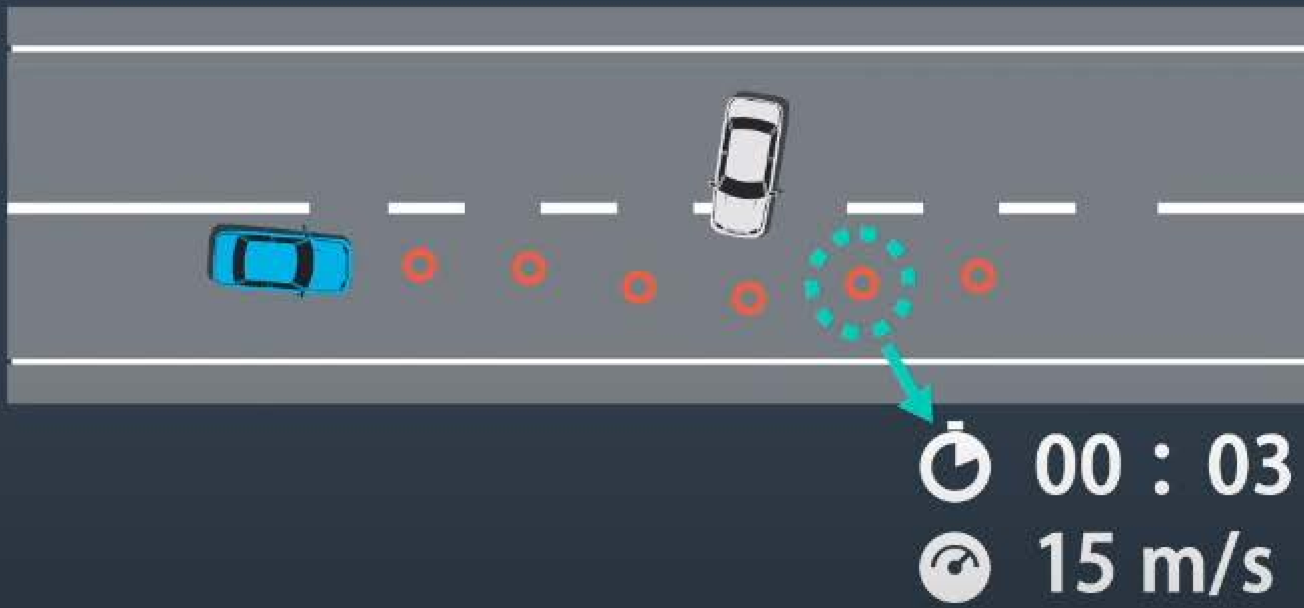
35,20,55

Things to think about

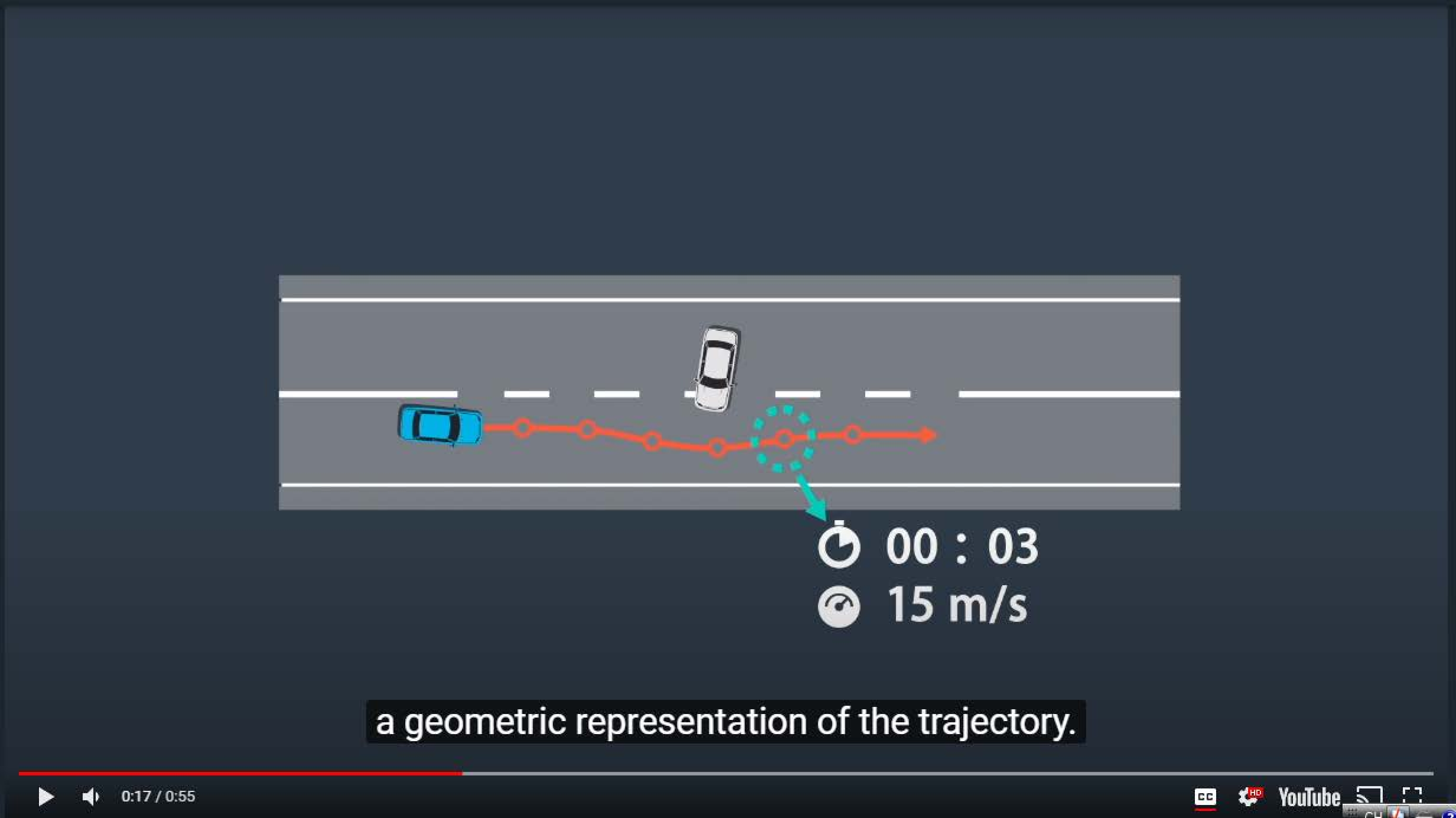
35, 20, 55

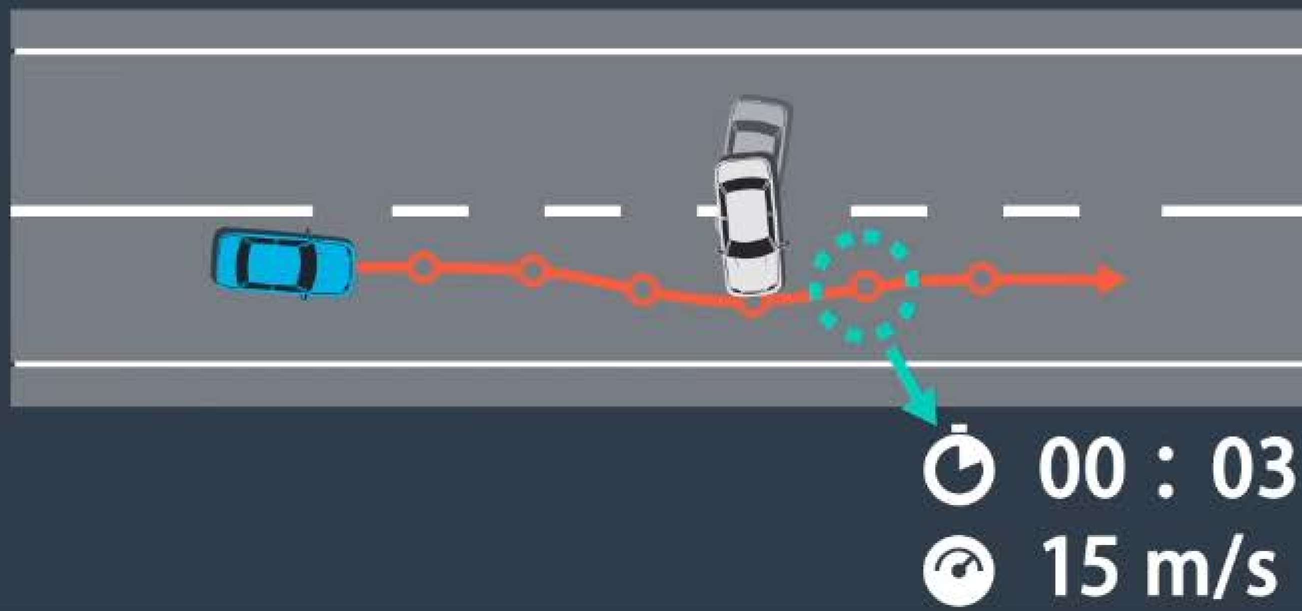
From Routing to Trajectories

SEND FEEDBACK



and a velocity to each way point,


00 : 03
15 m/s
a geometric representation of the trajectory.
0:17 / 0:55

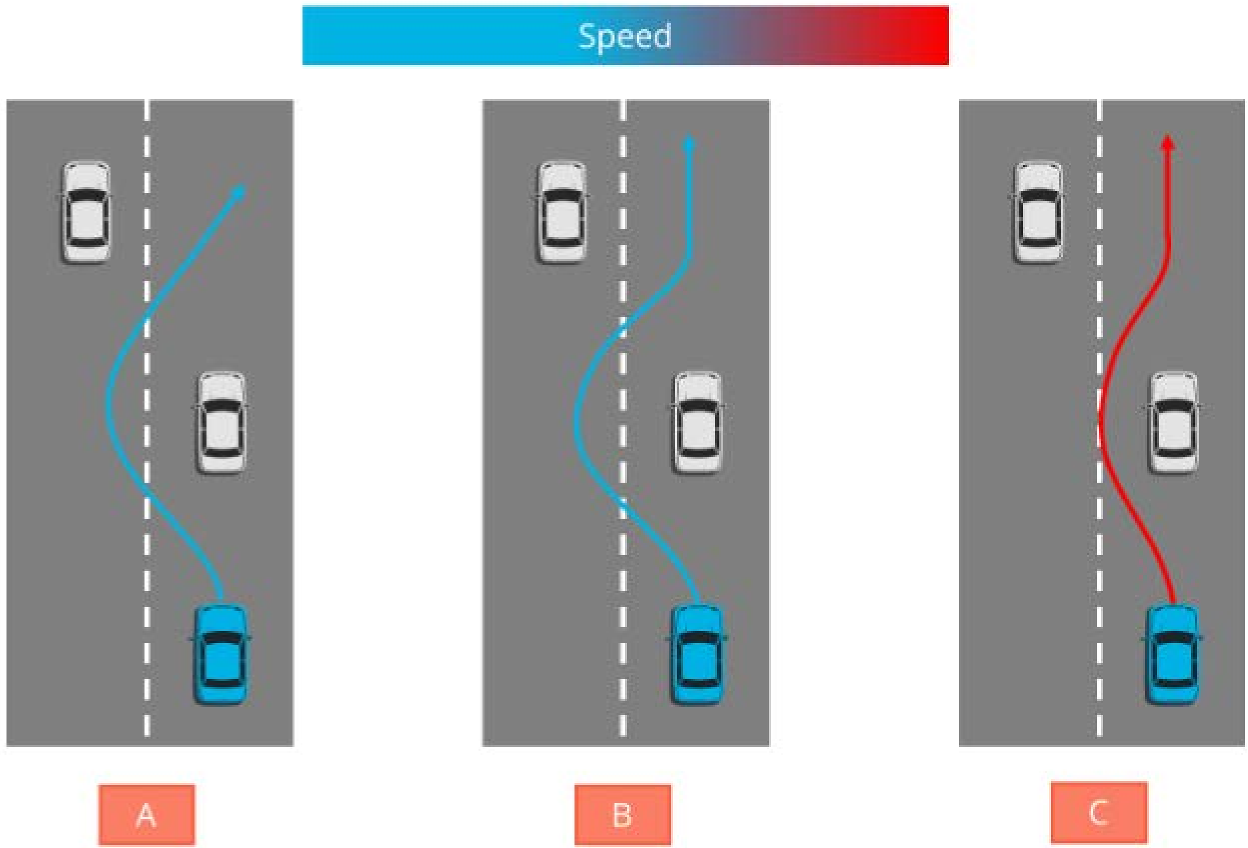


3D Trajectory: 2D Position + Time

each way point defined by two dimensions and space plus a third dimension in time.

QUIZ QUESTION

Let's test your intuition again. In the following scenario, each of the trajectories represents a planning scheme. Which of them looks the best to you?



- A
- B
- C

In the quiz above, did you consider the following aspects when evaluating each of the trajectories?

- [x] Whether the final position aligns with the center line of the lane
- [x] The distance from obstacles at every point of the trajectory
- [x] Whether our car will exceed speed limit when implementing the trajectory
- [x] Passengers' comfort

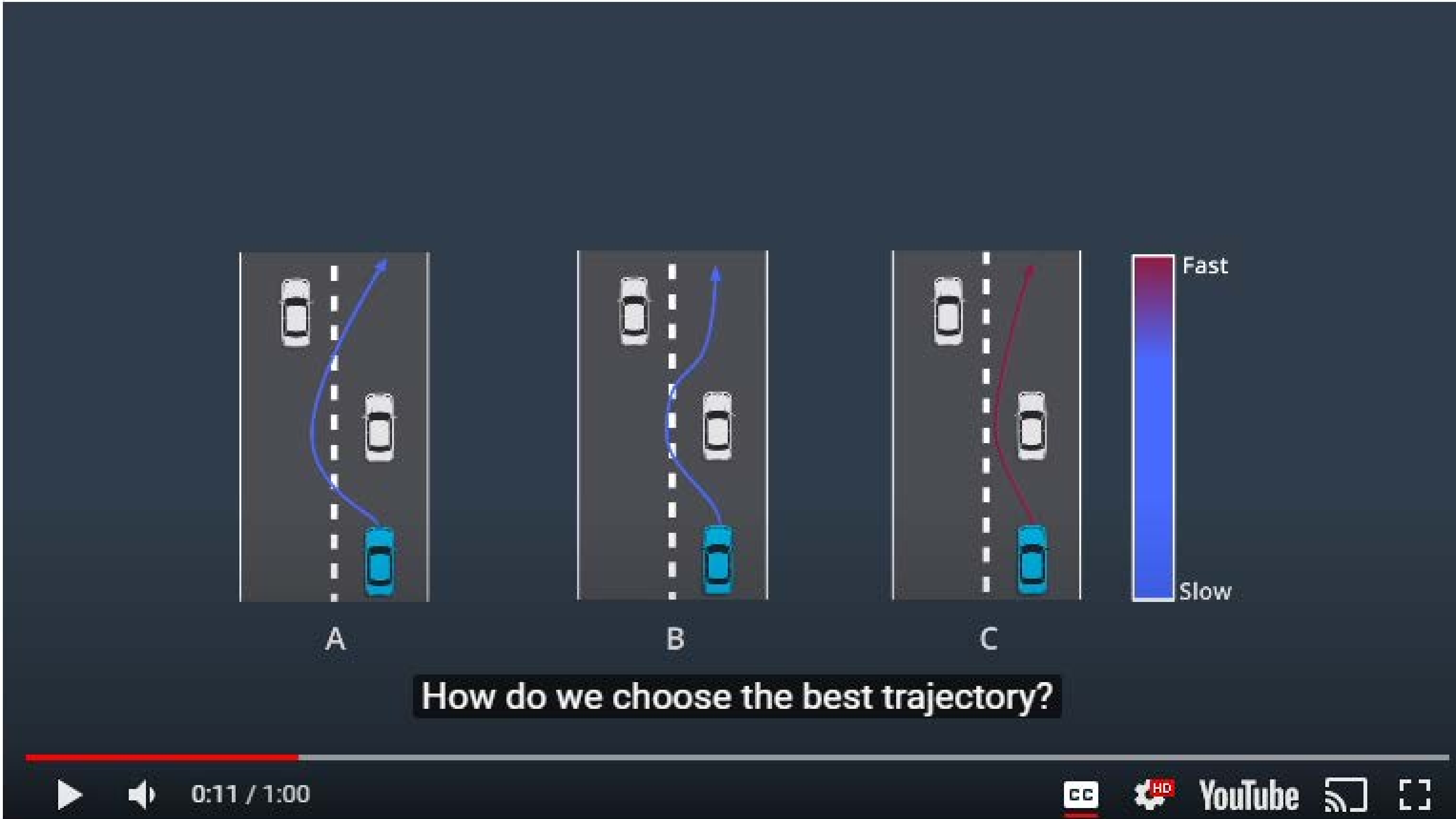
Constraints


Second, we want passengers to feel comfortable,
0:11 / 0:43
HD
YouTube

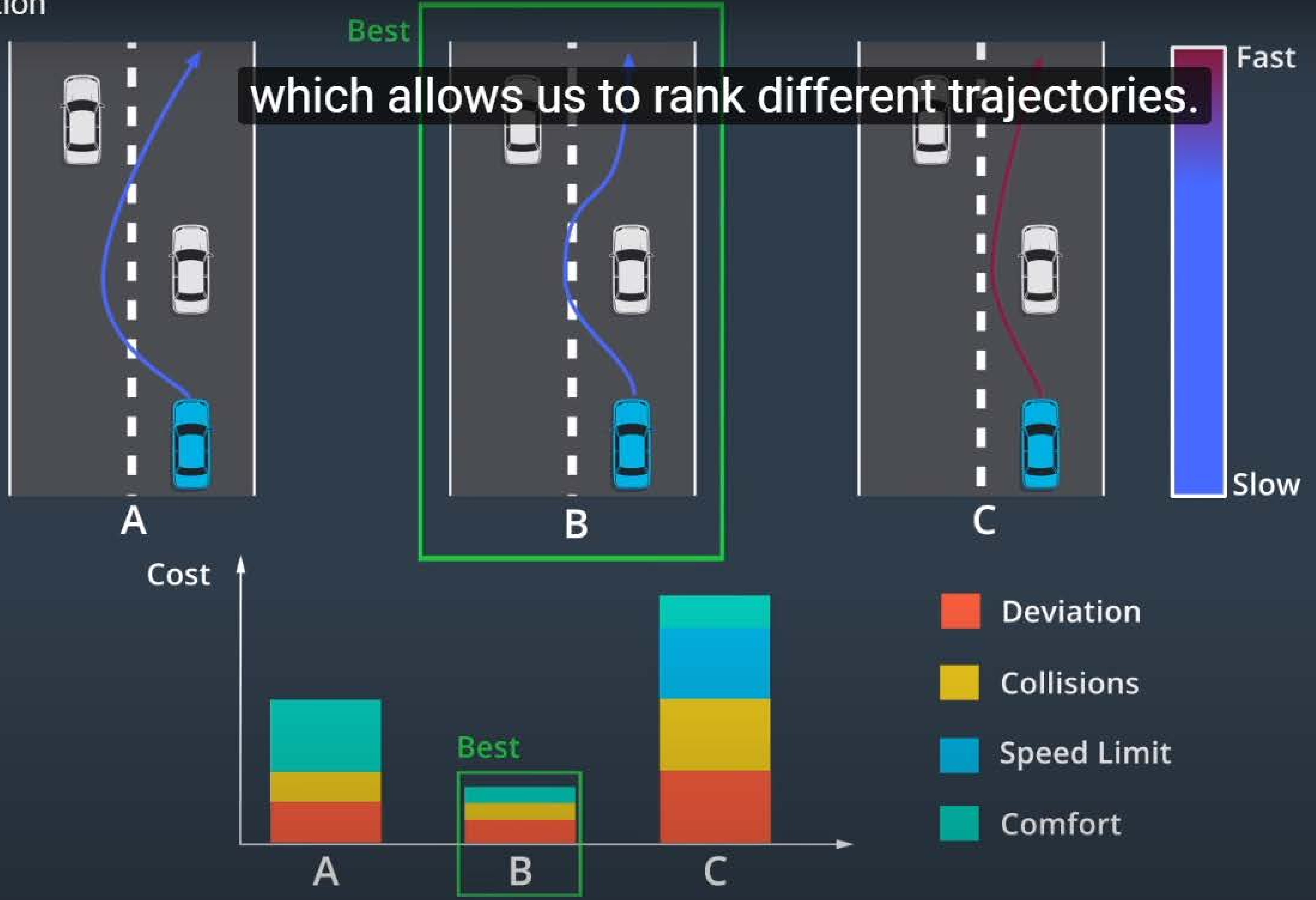

Third, the trajectory should be physically viable for the vehicle.
0:22 / 0:43
HD
YouTube


Finally, the trajectory should be legal.
0:35 / 0:43
HD
YouTube

Cost Function

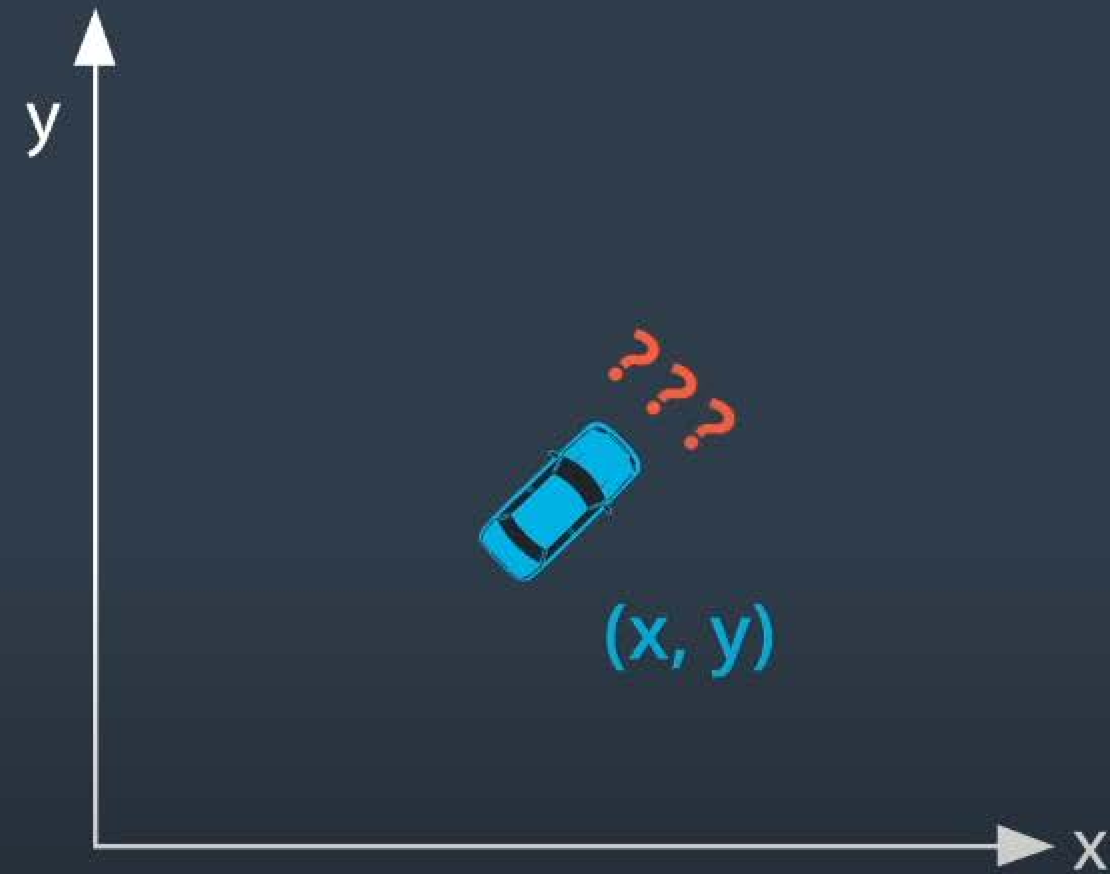


L6 Cost Function



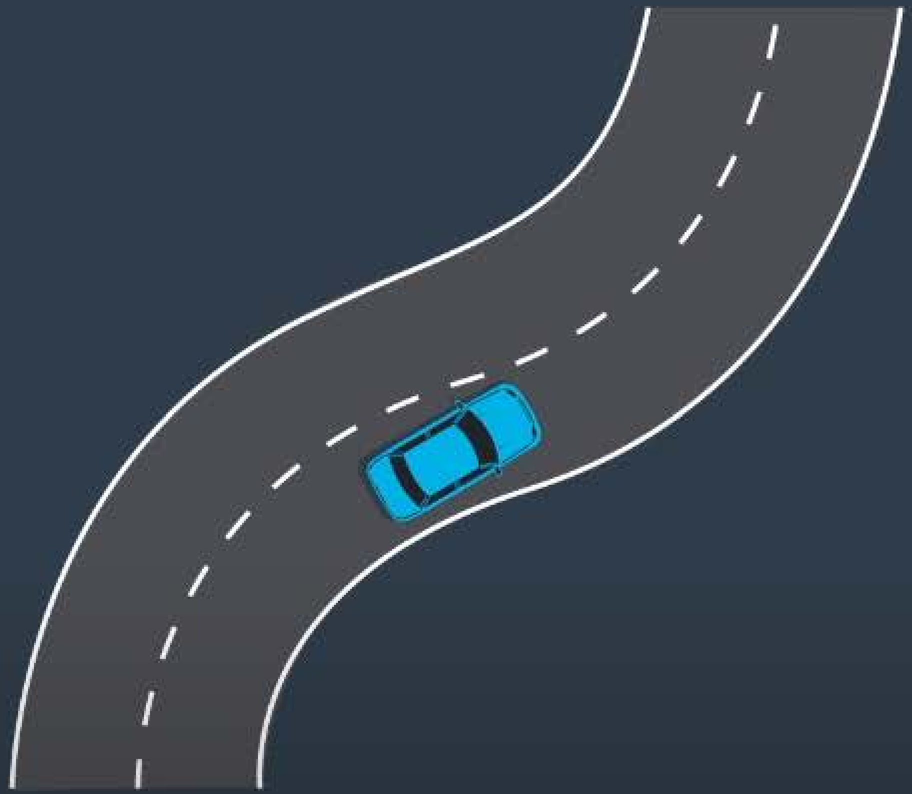
Watch later
Share
0:47 / 1:00

Cartesian Coordinates



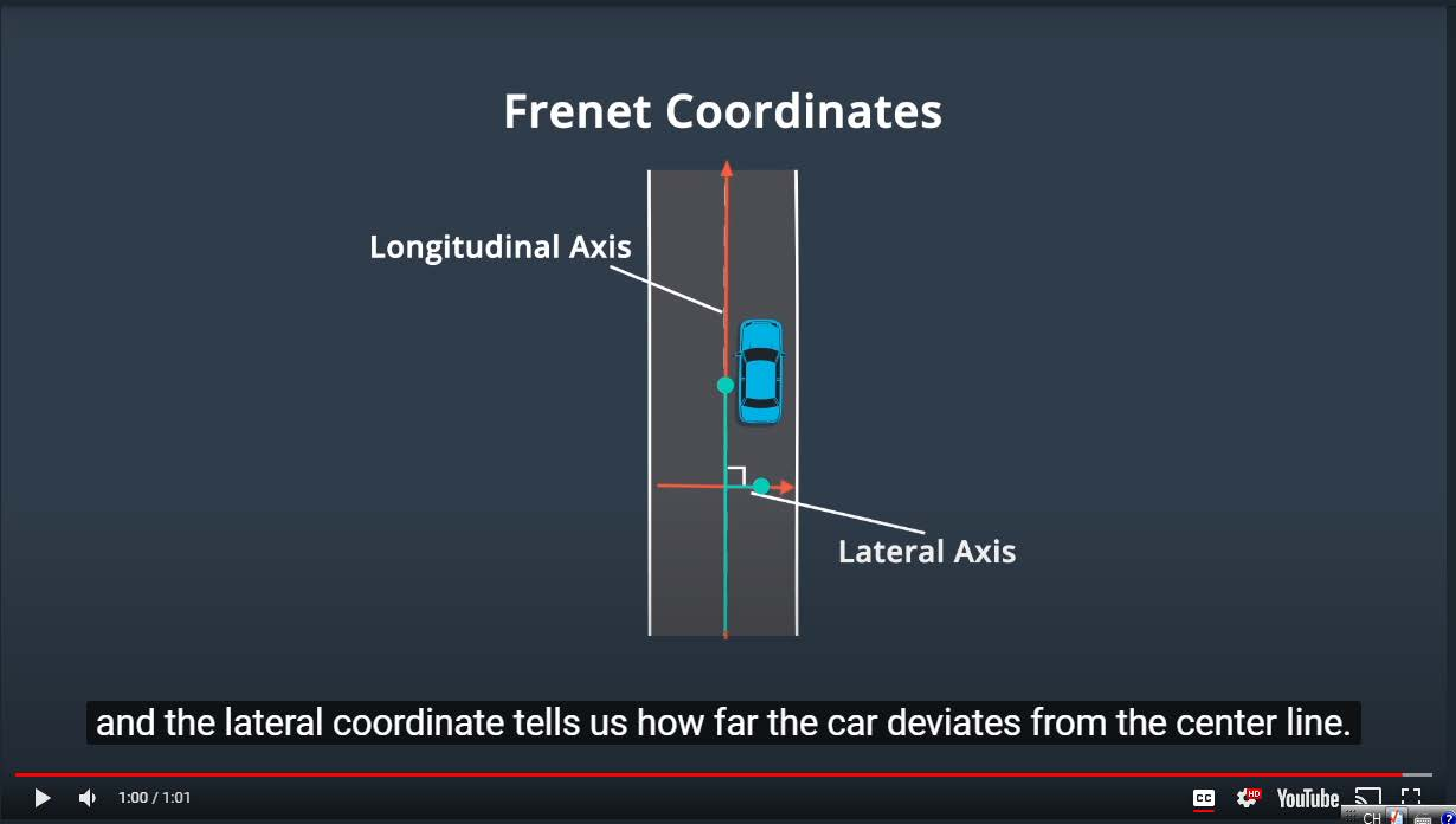
or whether it's deviated from the center of the lane.

Frenet Coordinates



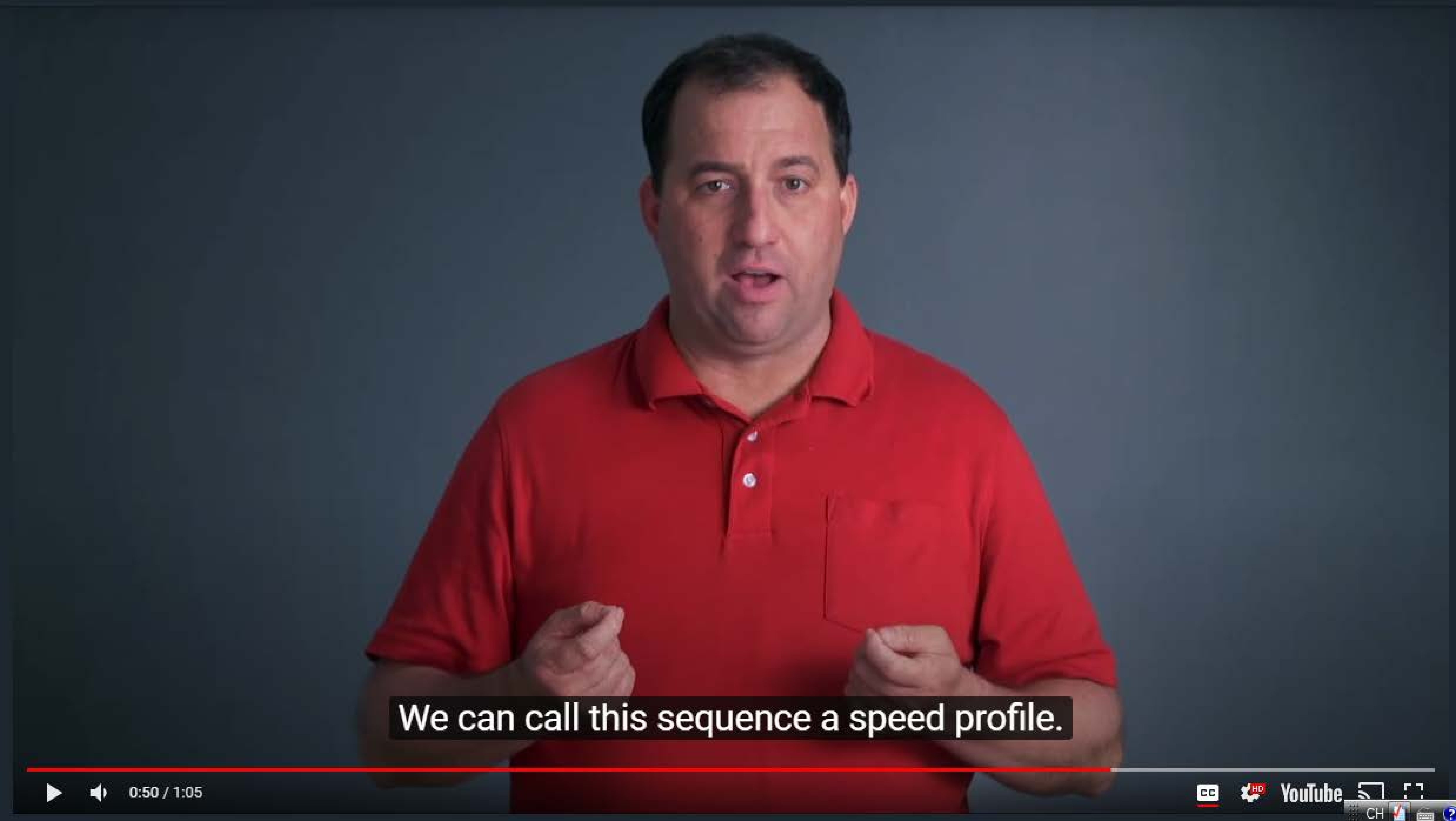
Frenet coordinates describe the position of a car with respect to the road.

0:29 / 1:01

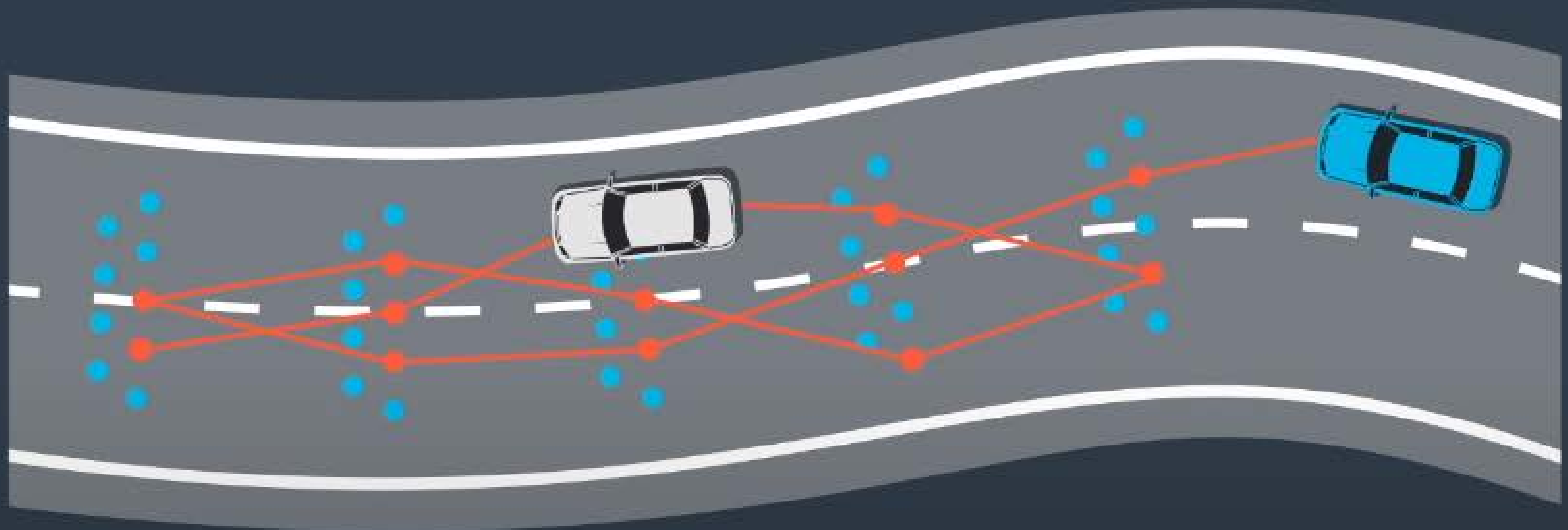

Frenet Coordinates
Longitudinal Axis
Lateral Axis
and the lateral coordinate tells us how far the car deviates from the center line.
1:00 / 1:01
YouTube

Path-Velocity Decoupled Plannning

SEND FEEDBACK


We can call this sequence a speed profile.
0:50 / 1:05
YouTube

Path Generation and Selection



We evaluate those paths using a cost function

Path Generation and Selection

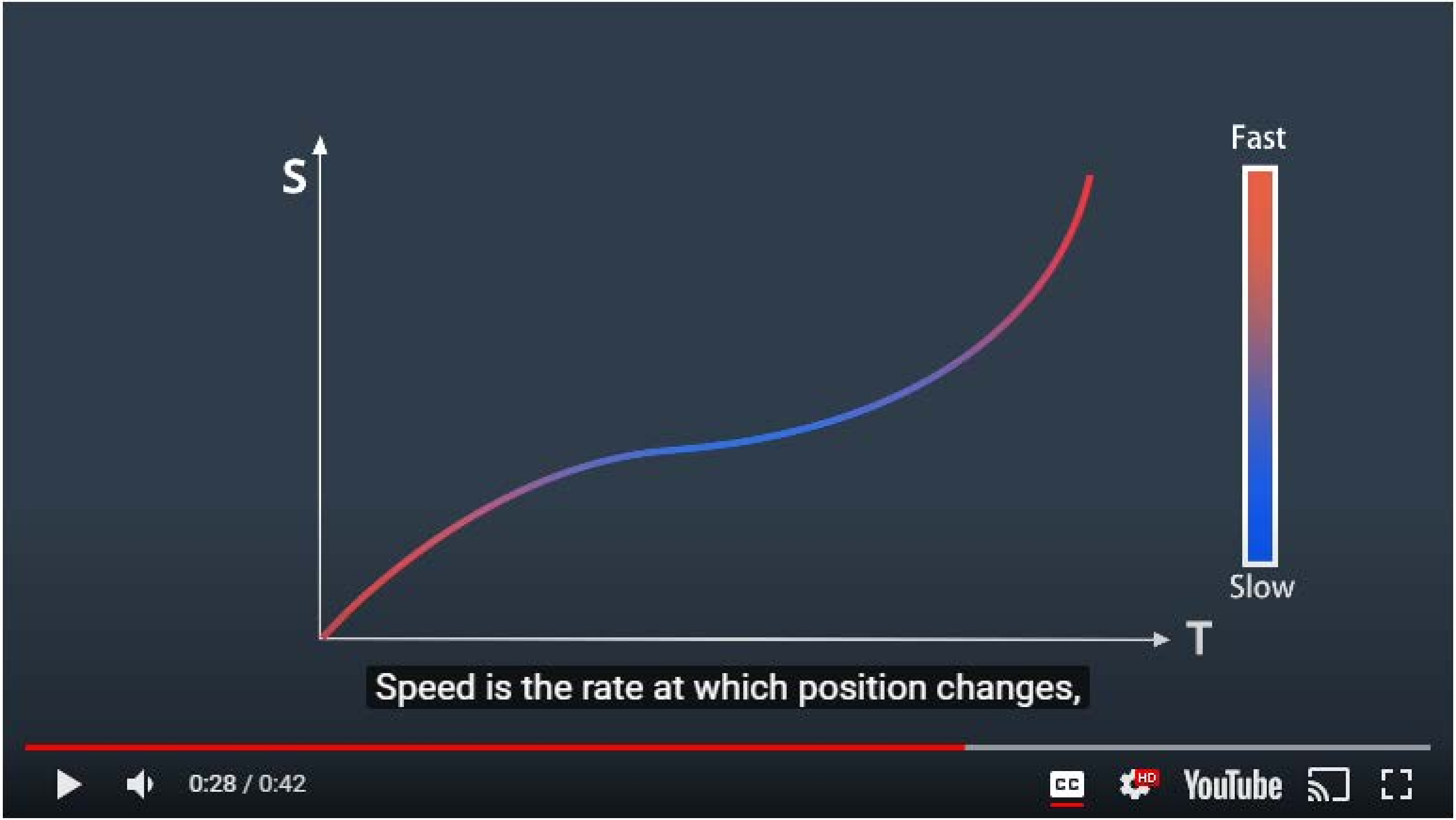
Cost function could take into account:

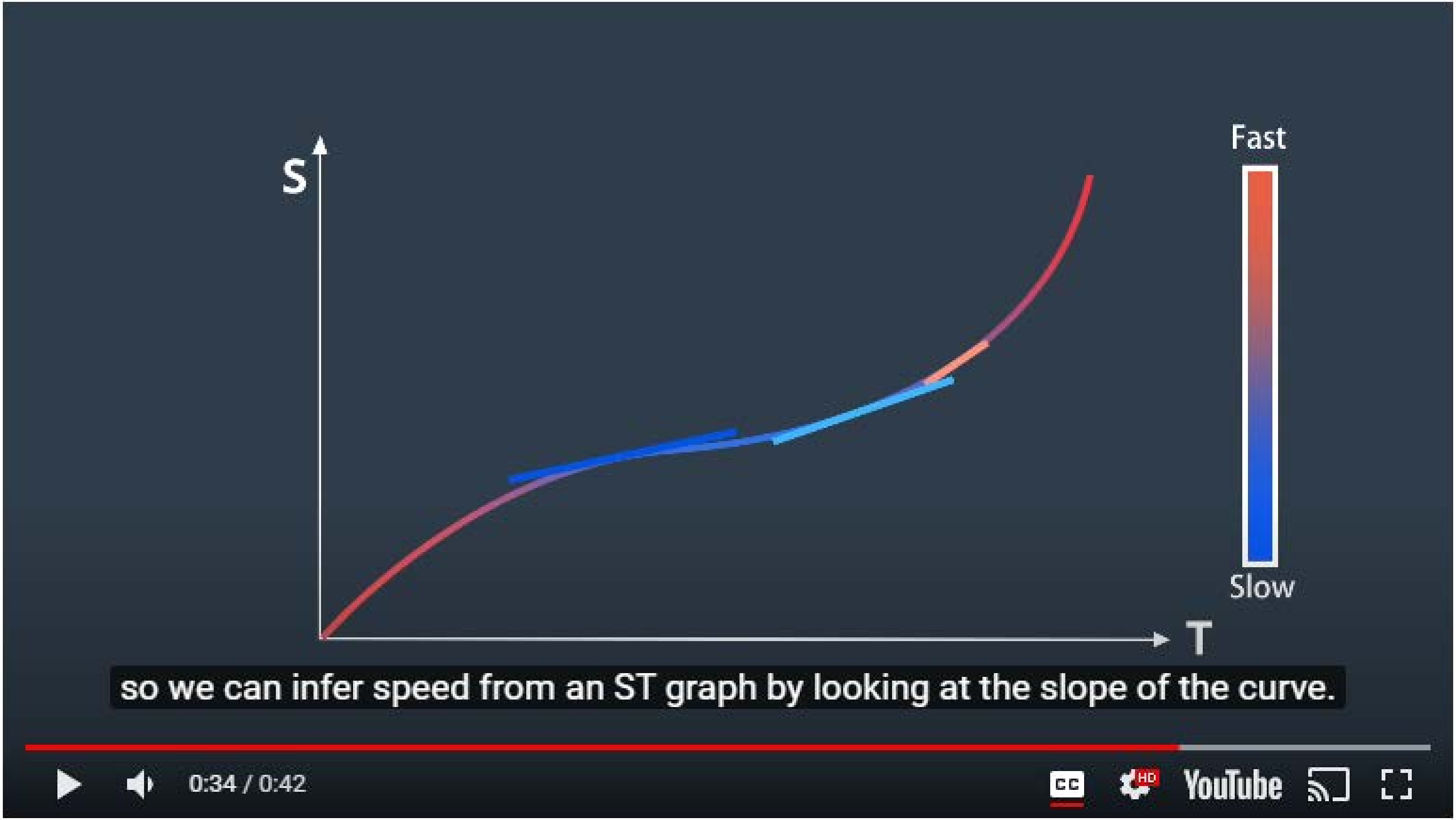
- Deviation from the center of the lane.
- Distance from obstacles.
- Changes in speed and curvature.
- Stress on the vehicle.

Or any other factors we want to include.


A tool called an ST graph can help us design and select the speed profile.
0:11 / 0:42
HD
YouTube

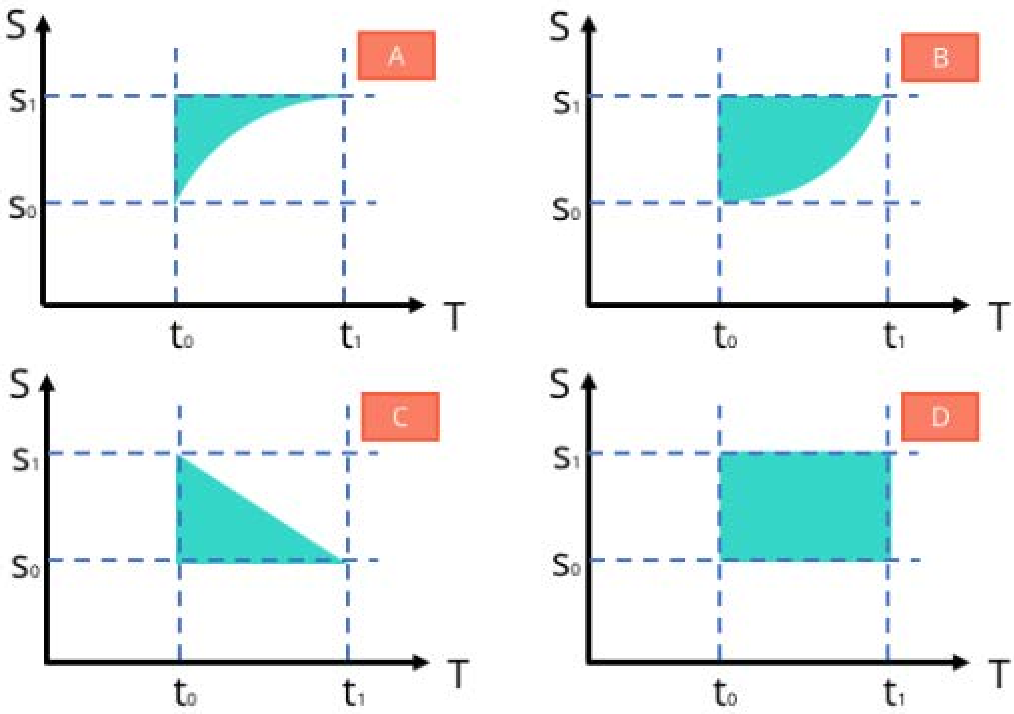

S
T
S represents the longitudinal displacement of the vehicle and T represents time.
0:19 / 0:42
HD
YouTube


S
T
Fast
Slow
Speed is the rate at which position changes,
0:28 / 0:42
YouTube


S
T
Fast
Slow
so we can infer speed from an ST graph by looking at the slope of the curve.
0:34 / 0:42
HD

QUIZ QUESTION

Suppose a vehicle is able to move in any direction and at any velocity. We know that the vehicle will travel between s0 to s1 in a period of t0 to t1. Which of the following shape represents all possible movements of the vehicle best?

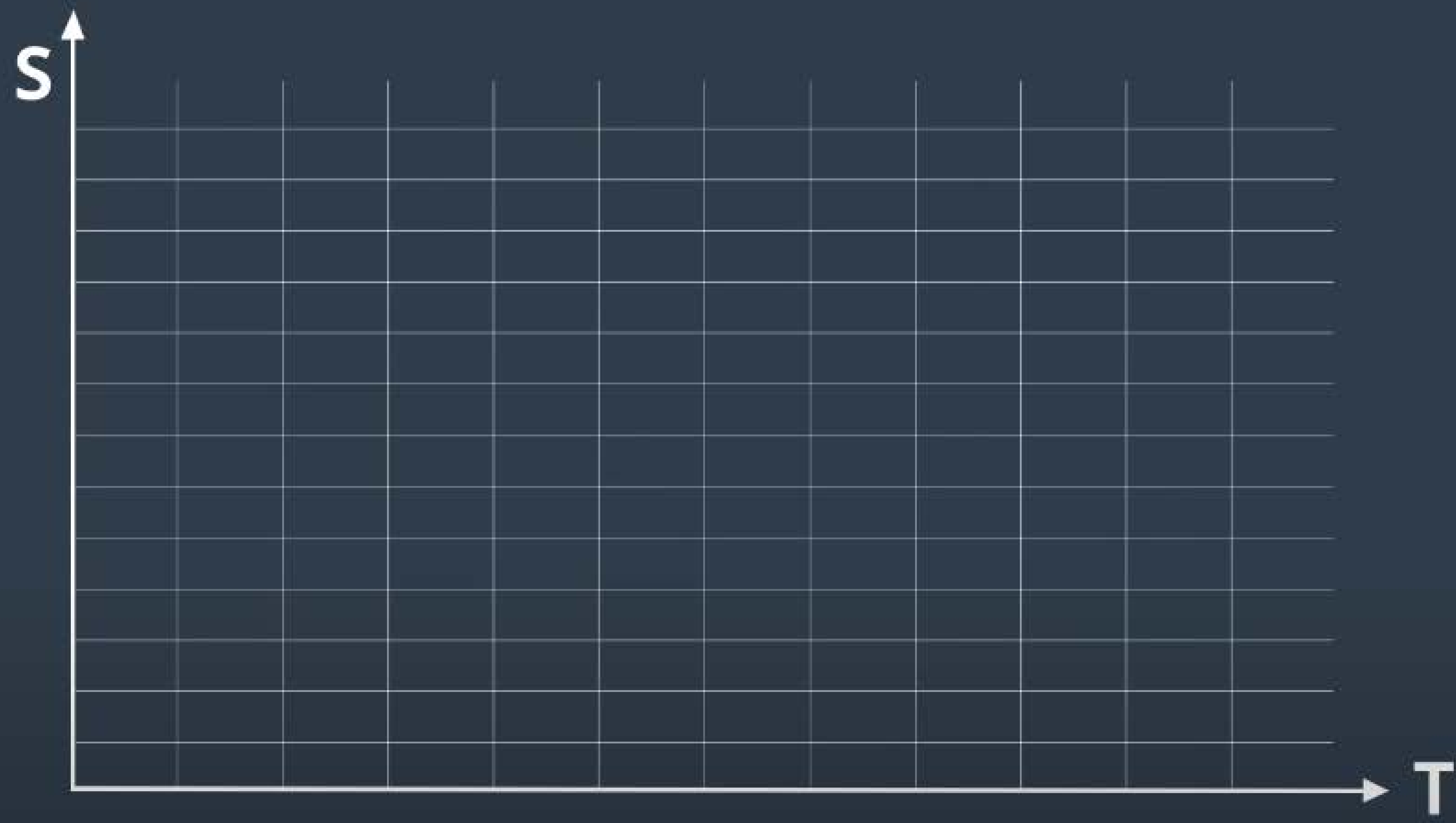


A

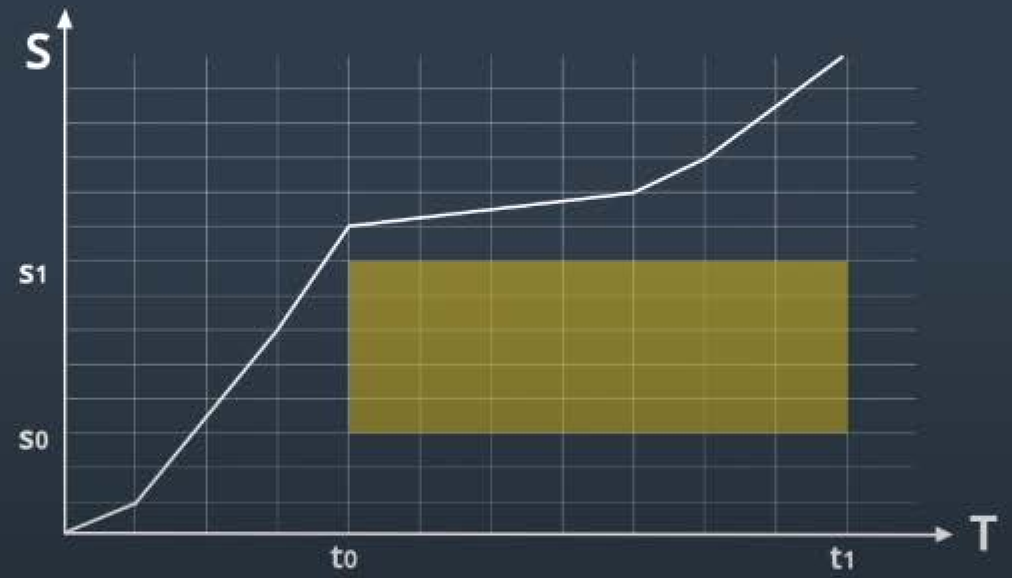
B

C

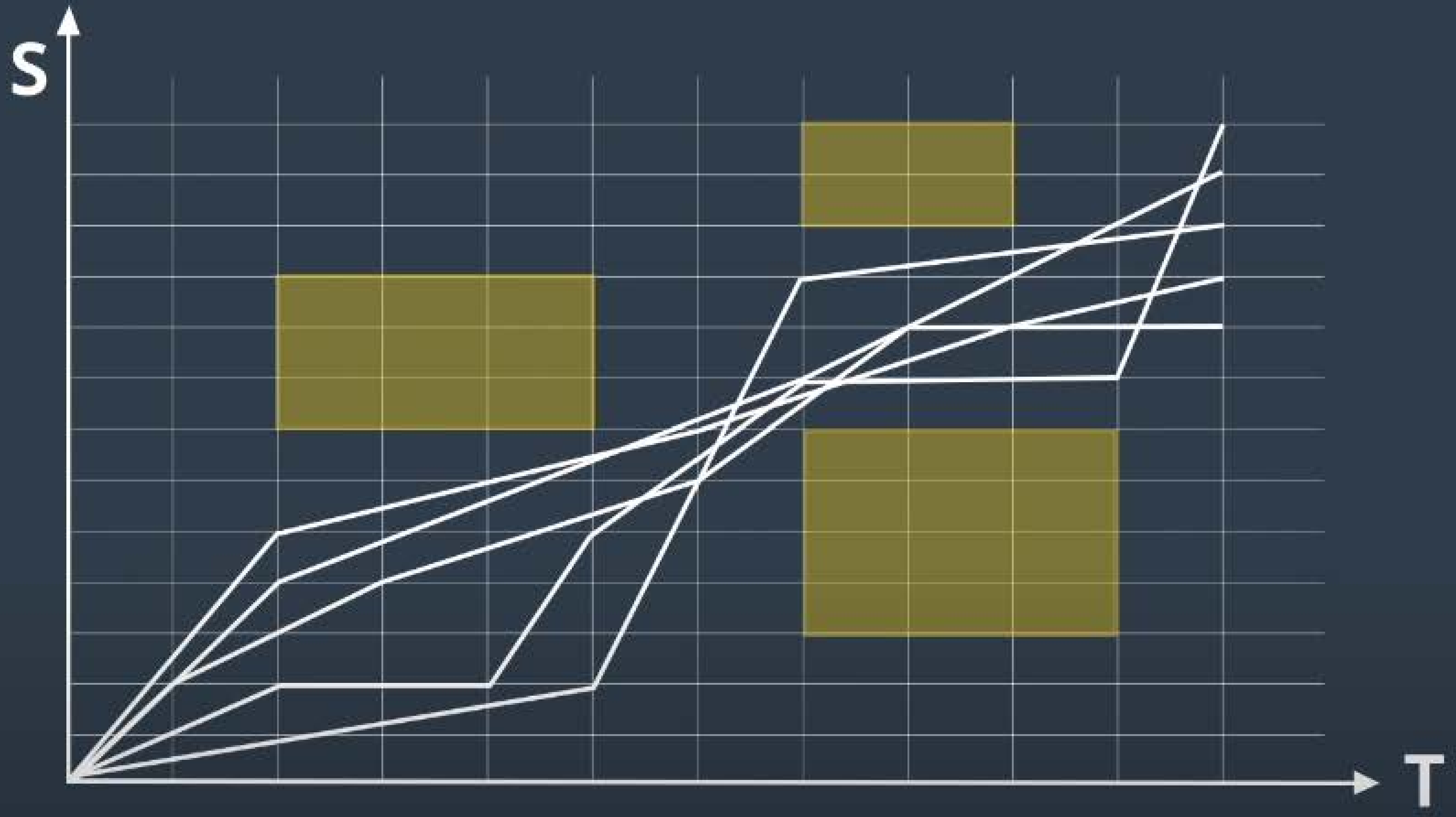
D



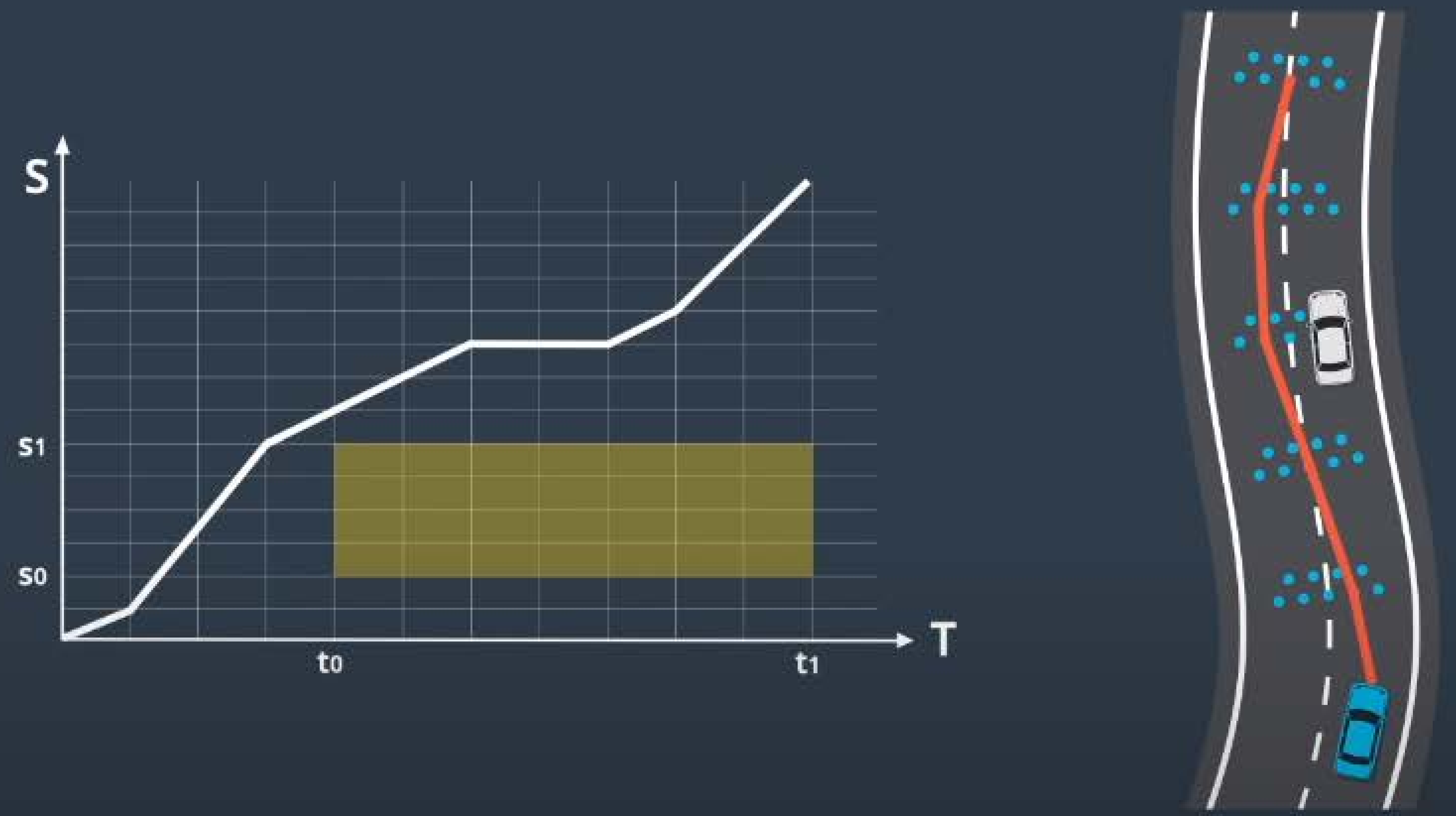
but within each cell, speed remains constant.



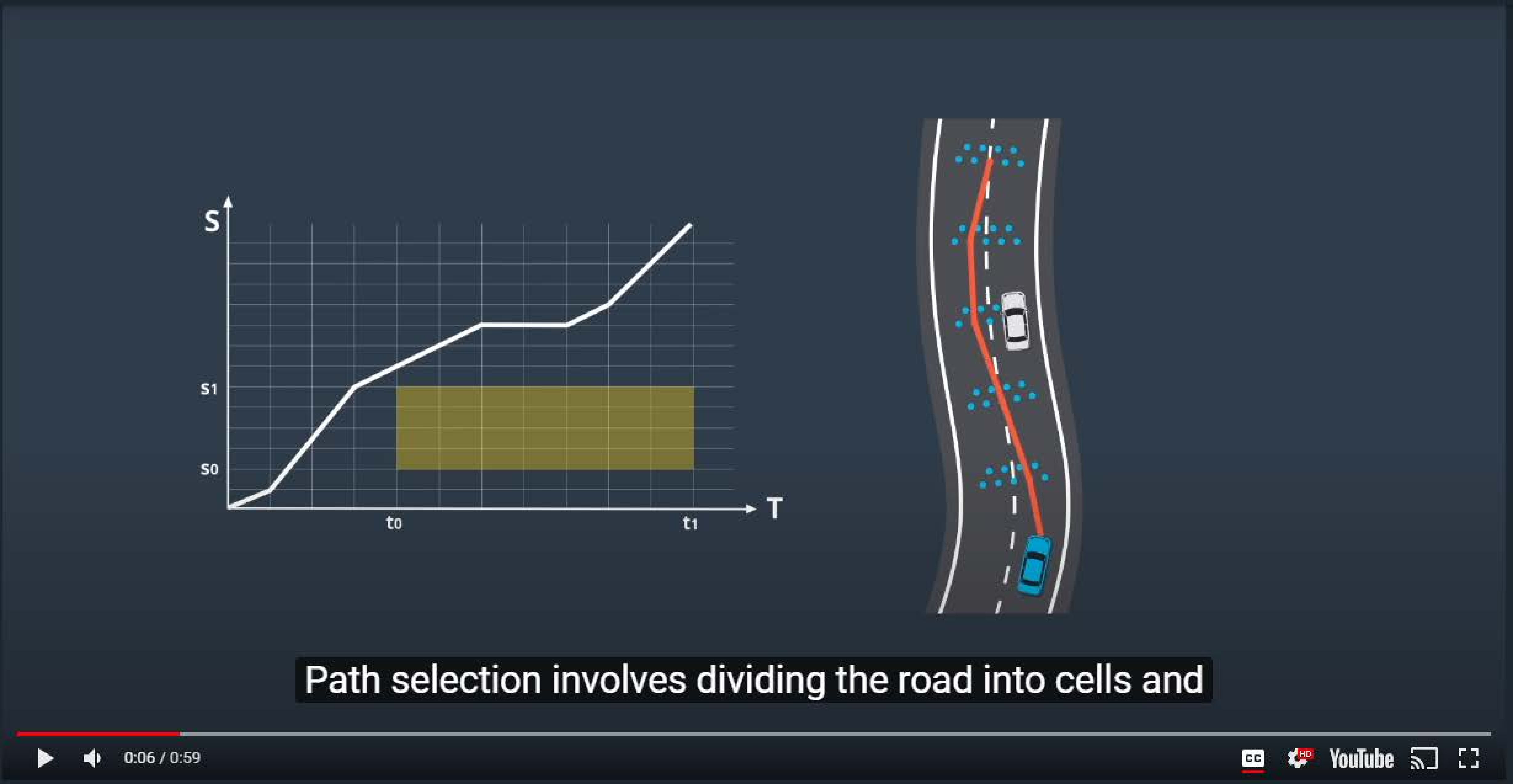
our speed profile must not intersect this rectangle.

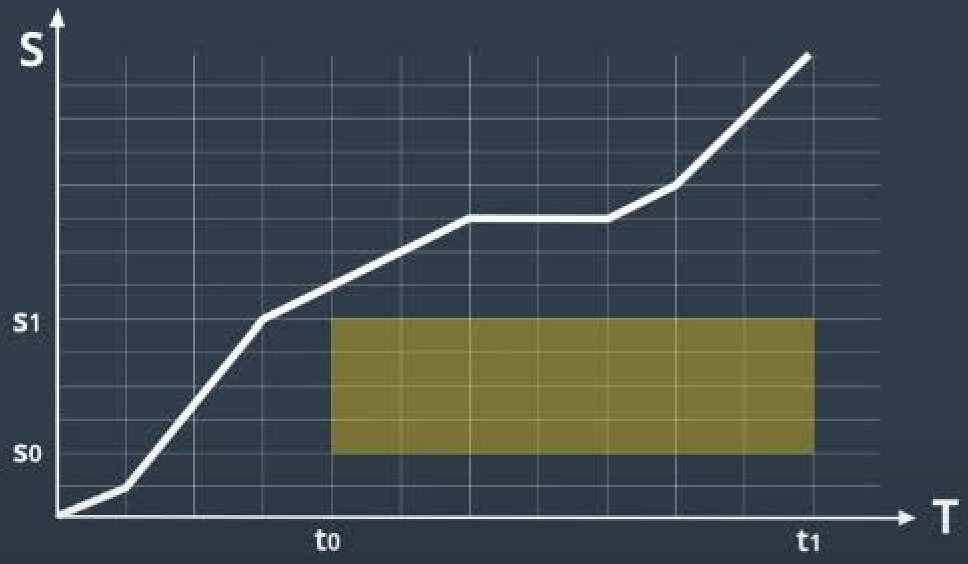


we can use an optimization engine to select the best speed profile for the graph.



Path-velocity decoupled planning depends heavily on discretization.


S
S1
S0
t0
t1
T
Path selection involves dividing the road into cells and
0:06 / 0:59
CC
HD
YouTube



speed profile construction involves dividing the ST graph into cells.

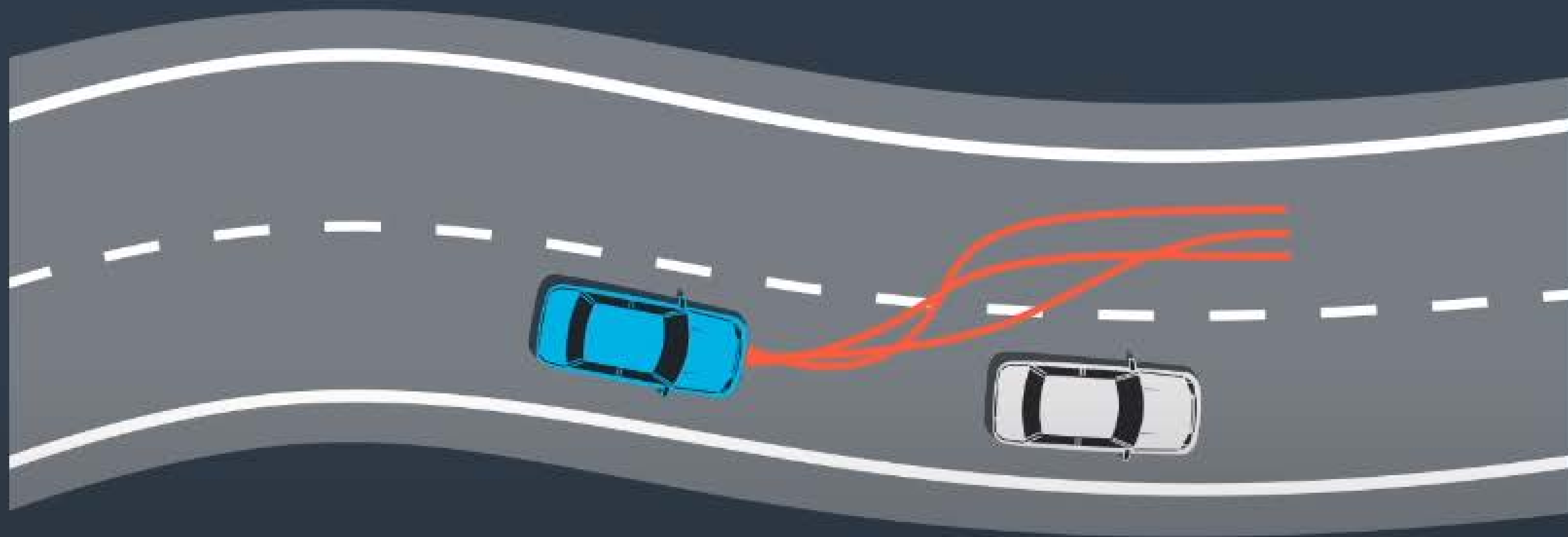
0:11 / 0:59

Quadratic Programming

we can use a technique called quadratic programming.

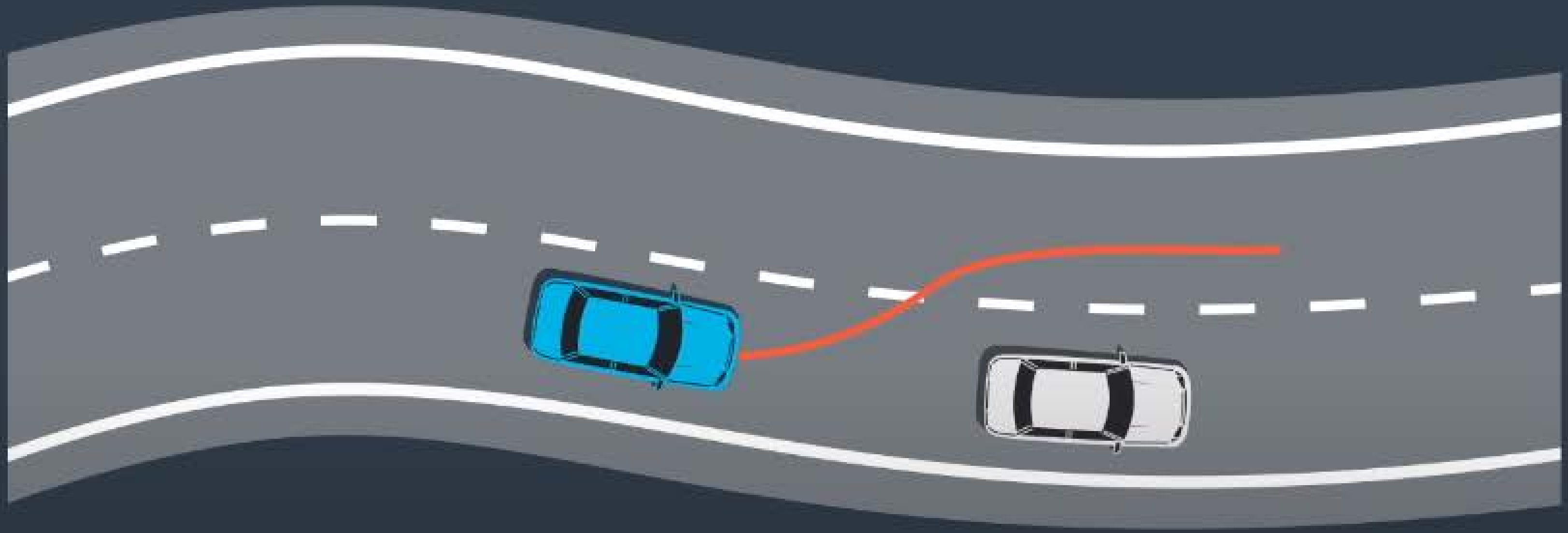
Trajectory Generation for Path Velocity Planning

SEND FEEDBACK



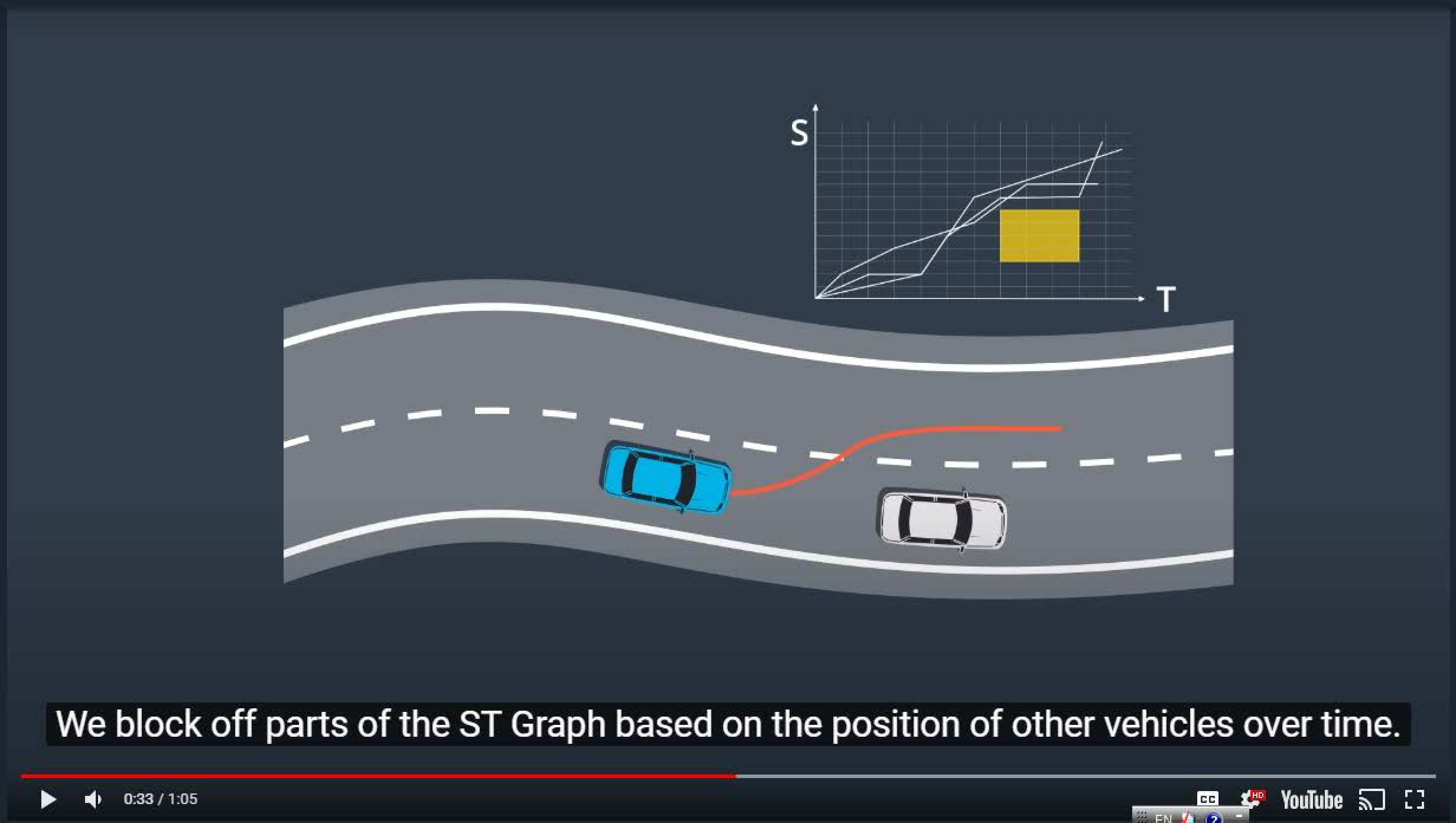
First, we generate multiple candidate paths around this vehicle.

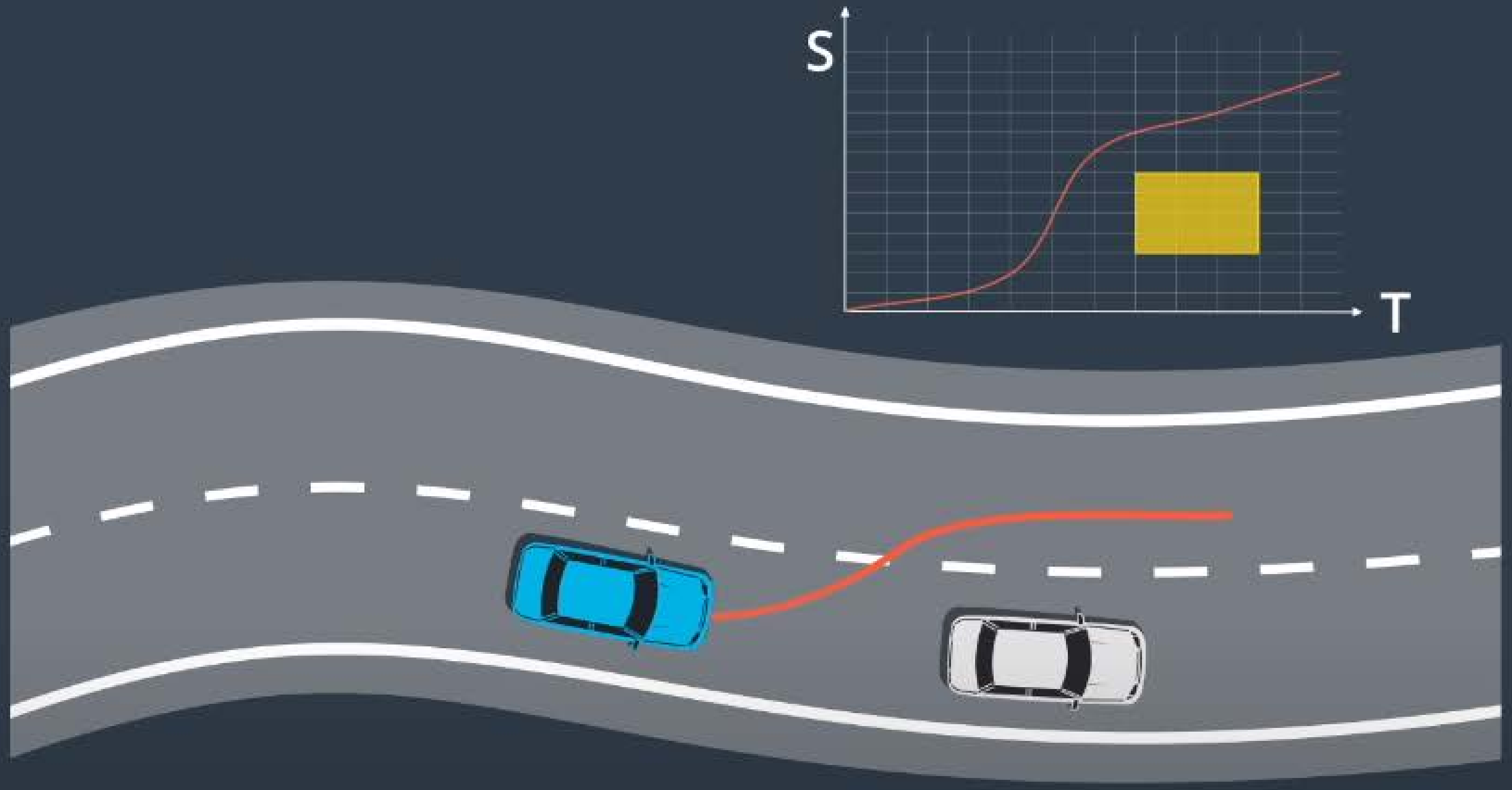
0:16 / 1:05



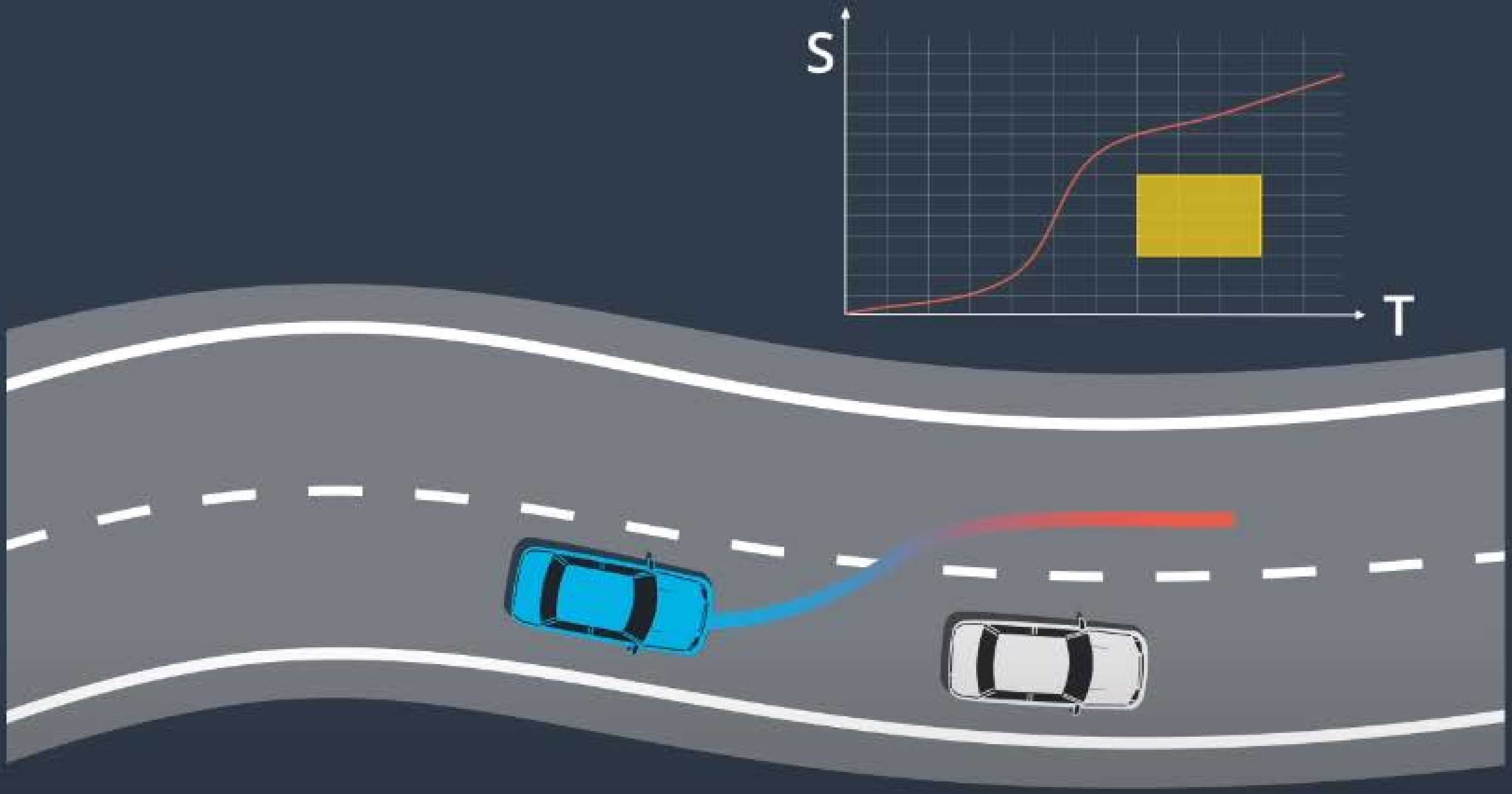
Then, we use an ST Graph for speed planning.

0:24 / 1:05


S
T
We block off parts of the ST Graph based on the position of other vehicles over time.
0:33 / 1:05
YouTube

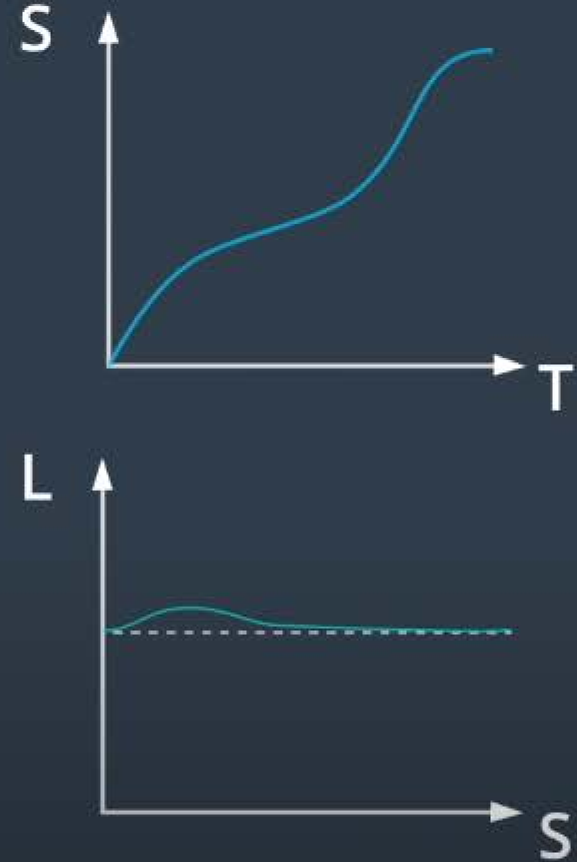


Finally, we can bind the path and speed profile together to construct a trajectory.

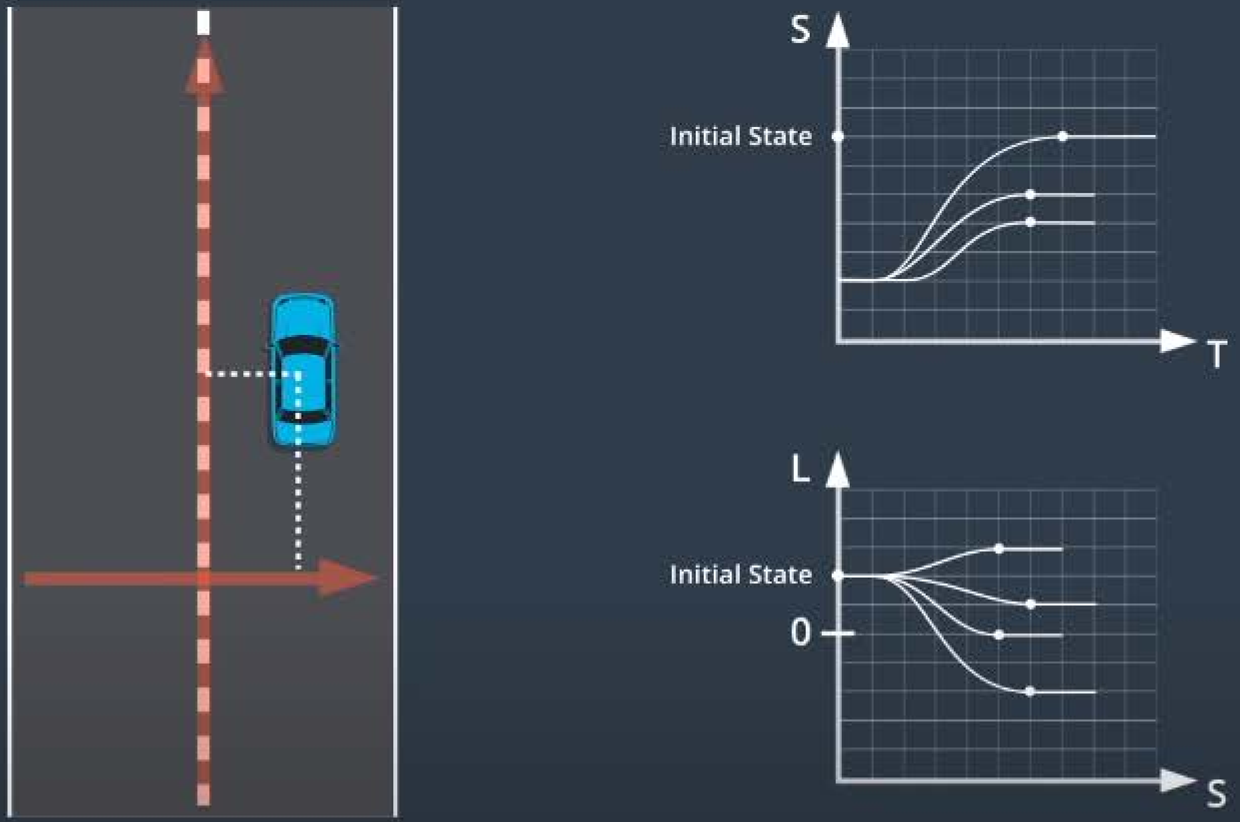


and blue where the speed is lower.

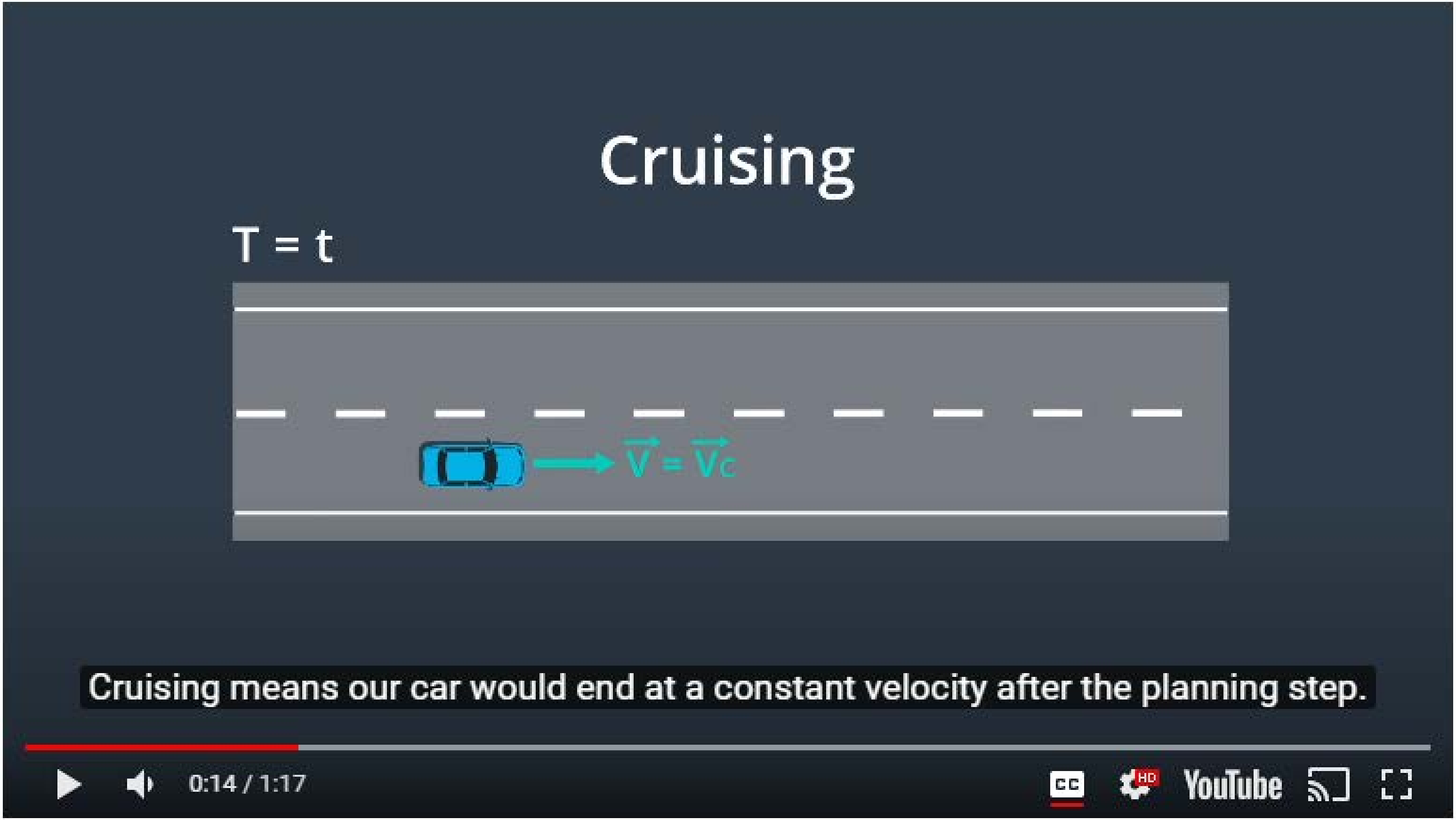
0:59 / 1:05



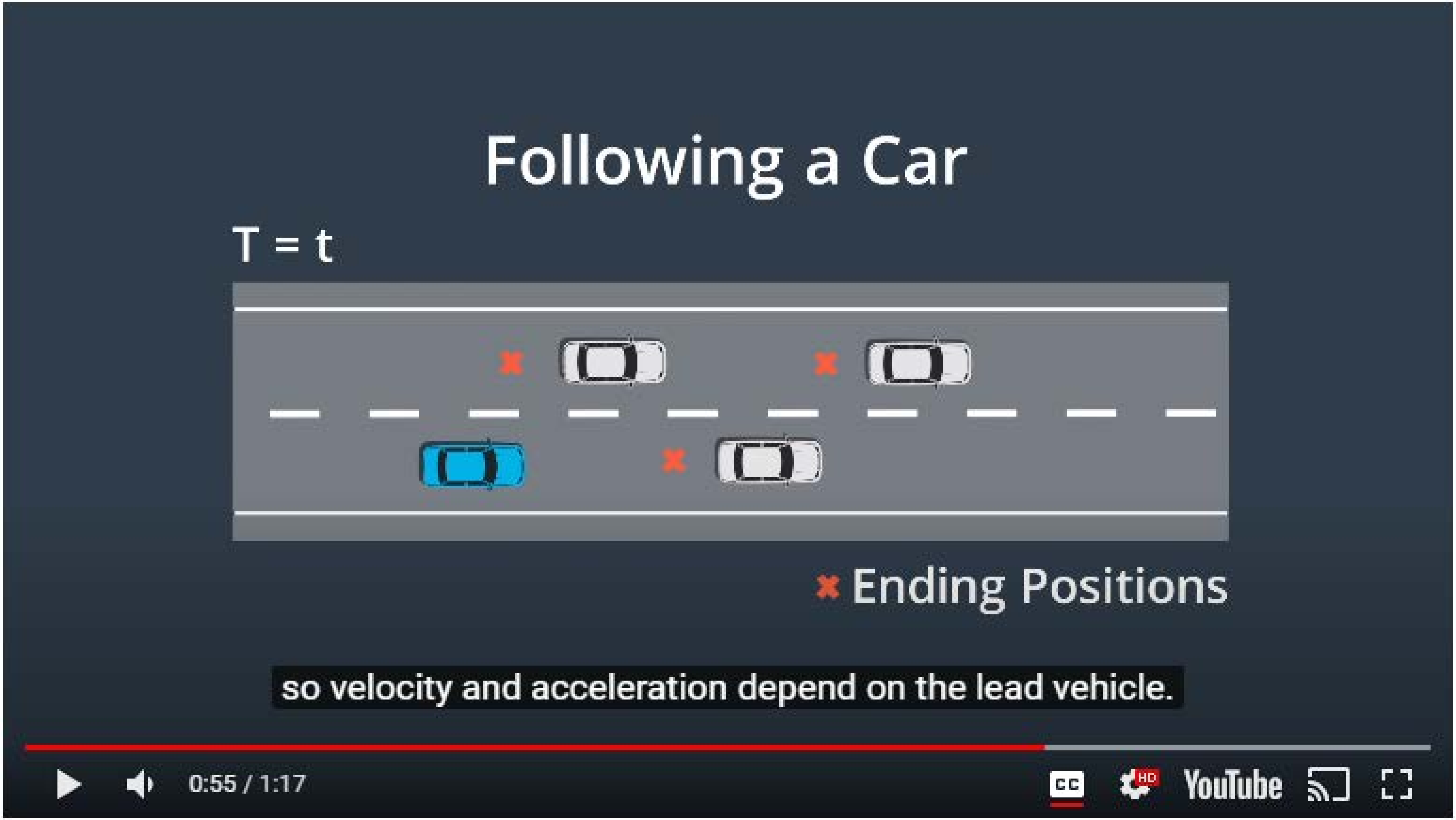
We call this the SL trajectory.

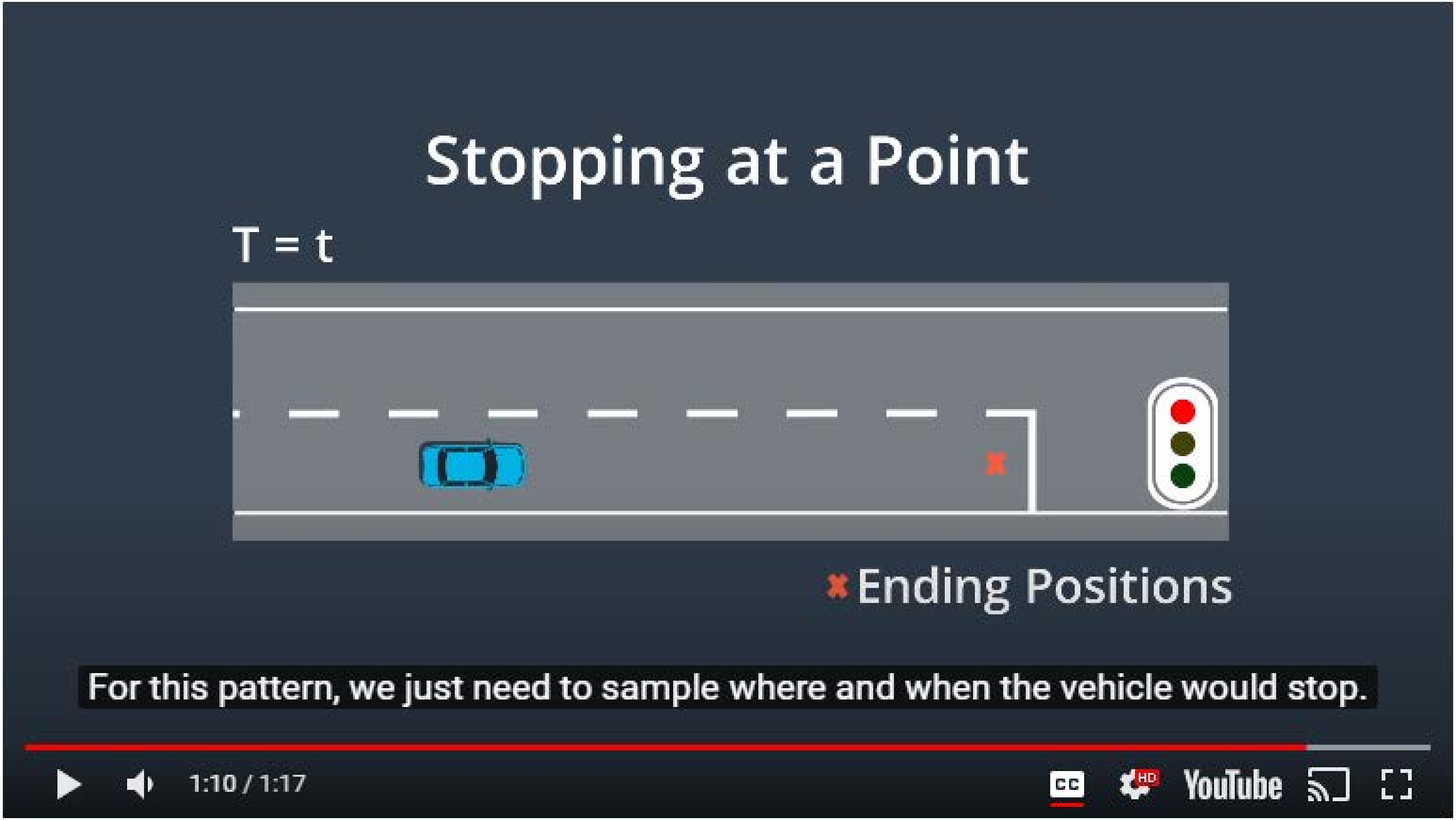


a cost function and select the lowest cost function trajectory.



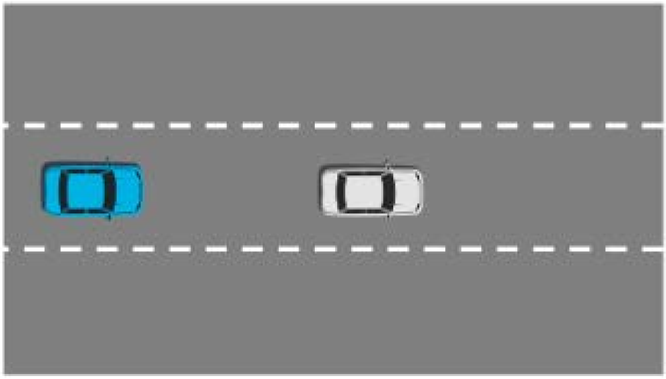
Cruising
T = t
V = Vc
Cruising means our car would end at a constant velocity after the planning step.
0:14 / 1:17
YouTube


Following a Car
T = t
Ending Positions
so velocity and acceleration depend on the lead vehicle.
0:55 / 1:17
HD
YouTube


Stopping at a Point
T = t
Ending Positions
For this pattern, we just need to sample where and when the vehicle would stop.
1:10 / 1:17
YouTube

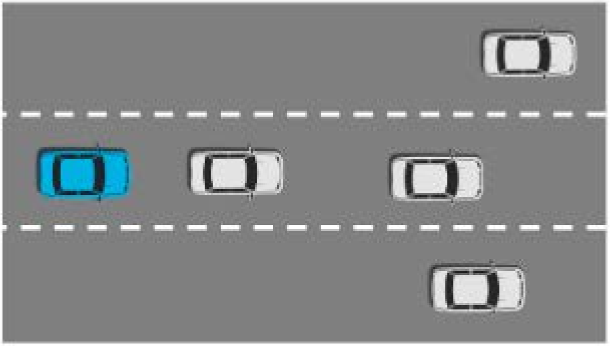
QUESTION 1 OF 3

In the following scenario, your task is to overtake the car in front of you. Despite what your target lane is or what car you are following, which of the following statements can always describe the final status after overtaking a car.



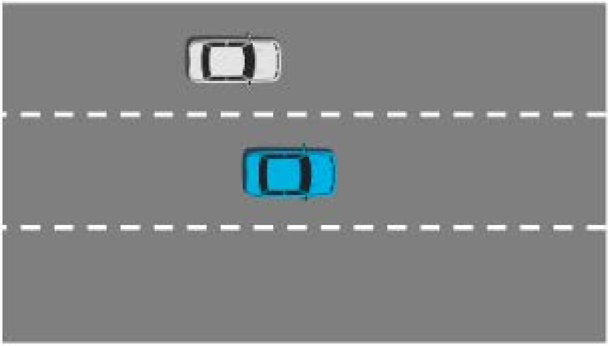
- [ ] The car steers left and go back to its lane.
- [x] The car cruises in a lane at some speed.
- [ ] The car steers left, accelerates, and steers right.
- [ ] The car cruises in front of a car at some speed

What about this scenario?

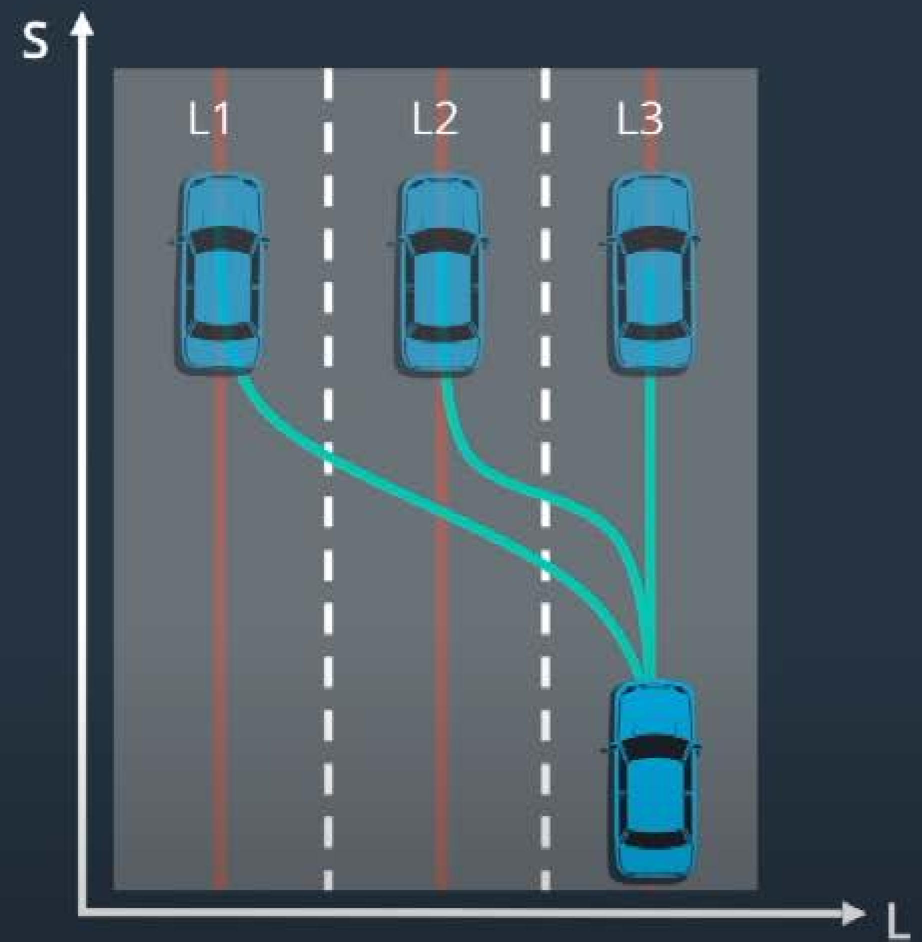


- The car steers to left and go back to its lane.
- The car cruises in a lane at some speed.
- The car steers to left, accelerates, and steers to right.
- The car follows an another car.

Try to consider all three types of pattern. Which is the best sampling pattern in the following scenario?



- [x] cruising
- [ ] follow a car
- [ ] stop at a point



should end with the vehicle aligned with the lane and driving straight.

Fit a polynomial and Evaluation

How do we connect the initial state and the ending state?

We will fit a polynomial to this two conditions. Here, the initial conditions and end conditions are both tuples with position, speed, and acceleration on s coordinate. Note that speed is the first order derivative of position and acceleration is the second order derivative of position. Usually, we denote the derivative with respect to time as a dot above a variable.

So for initial condition, we have : $(s_0, \dot{s_0}, \ddot{s_0})$

and for ending conditions, we have: $(s_1, \dot{s_1}, \ddot{s_1})$

The polynomial we are going to fit looks like:

$$s(t) = at^5 + bt^4 + ct^3 + dt^2 + et + f$$

By taking the derivative of this form we get:

$$s(\dot{t}) = 5at^4 + 4bt^3 + 3ct^2 + 2dt + e$$

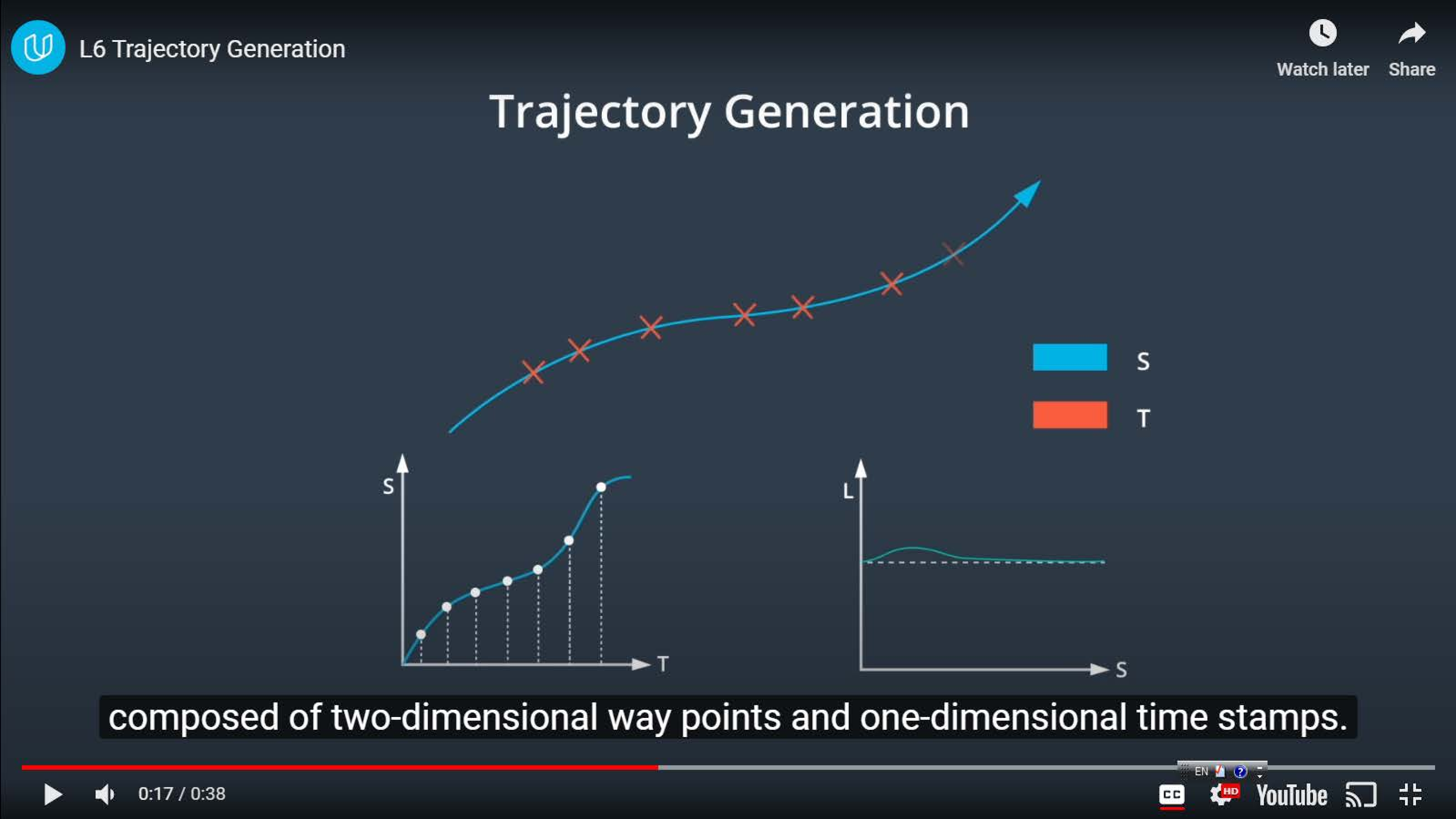
and

$$s(\ddot{t}) = 20at^3 + 12bt^2 + 6ct + 2d$$

Now we plug in the initial condition and ending condition, we have 6 equations. Here we suppose the ending condition happen at time $t = T$.

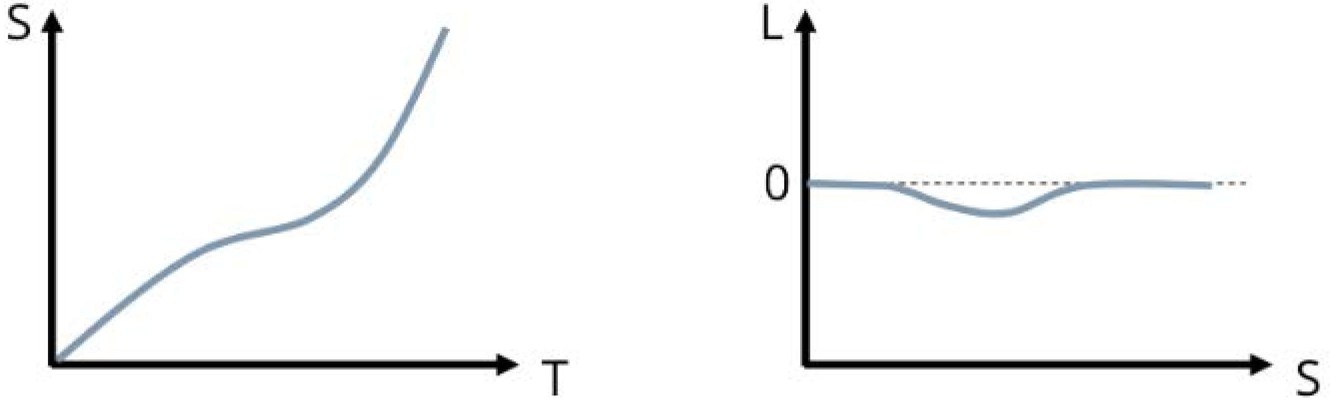
$$s_0 = f$$
$$\dot{s}_0 = e$$
$$s_0 = 2d$$
$$s_1 = aT^5 + bT^4 + cT^3 + dT^2 + eT + f$$
$$\dot{s}_1 = 5aT^4 + 4bT^3 + 3cT^2 + 2dT + e$$
$$\ddot{s}_1 = 20aT^3 + 12bT^2 + 6cT + 2d$$

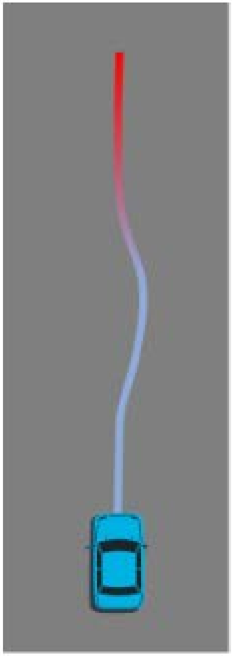
With these equations, we can solve for a, b, c, d, e, and f. This represents a curve that smoothly connects two conditions.


L6 Trajectory Generation
Watch later
Share
Trajectory Generation
S
T
S
T
L
S
composed of two-dimensional way points and one-dimensional time stamps.
0:17 / 0:38

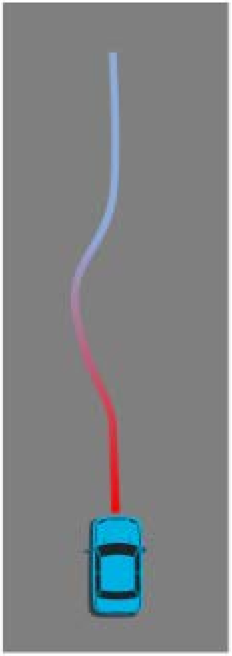
QUIZ QUESTION

Which of the following trajectories are generated from this pair of ST and SL trajectories? (Red represents higher speed)

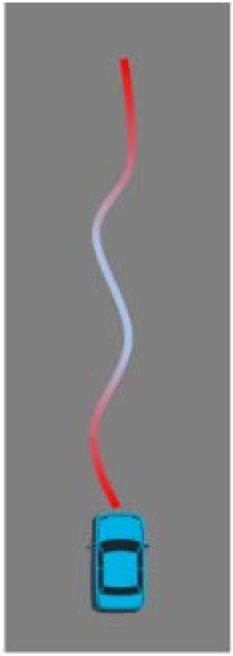




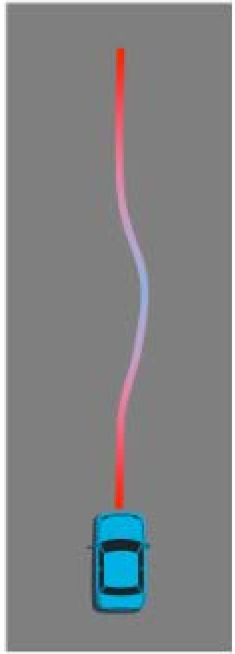
A



B



C



D

- A
- B
- C
- D ✓