

## 1 | shoestring loop

$$\begin{aligned}
 x &= t^2 \\
 y &= t^3 - 3t \\
 \frac{dx}{dt} &= 2t \\
 \frac{dy}{dt} &= 3t^2 - 3 \\
 \frac{dy}{dx} &= \frac{3t^2 - 3}{2t}
 \end{aligned}$$

### 1.1 | tangents are horizontal or vertical

#### 1.1.1 | horizontal

$$\begin{aligned}
 3t^2 - 3 &= 0 \\
 3t^2 &= 3 \\
 t^2 &= 1 \\
 t &= \pm 1
 \end{aligned}$$

#### 1.1.2 | vertical

$$\begin{aligned}
 2t &= 0 \\
 t &= 0
 \end{aligned}$$

### 1.2 | concave up

$$\begin{aligned}
 \frac{d}{dx} \frac{dy}{dx} &= \frac{\dot{x}\ddot{y} - \dot{y}\ddot{x}}{\dot{x}^3} = \frac{2t(6t) - (6t^2 - 3)(2)}{8t^3} \\
 &= \frac{6t^2 - 6t^2 + 3}{4t^3} = \frac{3}{4t^3} > 0 \\
 &\therefore \text{concave up for } t > 0
 \end{aligned}$$

### 1.3 | concave down

Using similar logic, the curve is concave down for  $t < 0$ .

## 2 | polar curves + converting to cartesian

polar sketches

Also see the desmos.