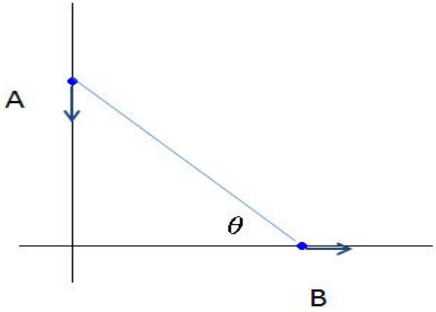
April 20 Math 1190 sec. 62 Spring 2017

Section 4.1: Related Rates

Pedestrians A and B are walking on straight streets that meet at right angles. A approaches the intersection at 2m/sec, and B moves away from the intersection at 1m/sec. Our goal is to determine the rate at which the angle θ shown in the diagram is changing when A is 10m from the intersection and B is 20 m from the intersection?



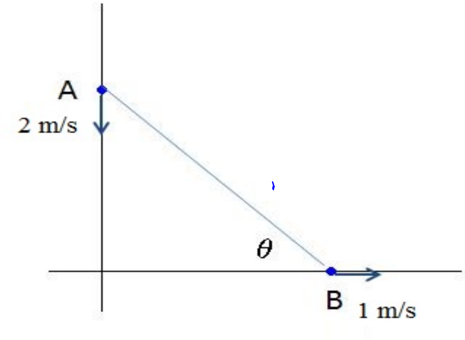
Question

Let $A(t)$ be pedestrian A's position (distance to intersection), and $B(t)$ be pedestrian B's position. Let's make some observations:

(a) **True or False** A is decreasing.
(b) **True or False** B is increasing.

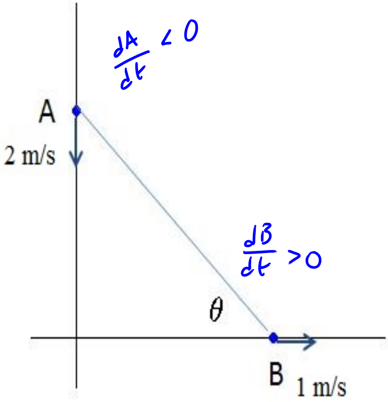
A walks toward intersection.

B walks away.



Question

From the diagram, which of the following are the rates of change of A and B (in m/s)?



(a) $\dfrac{dA}{dt} = -2$ and $\dfrac{dB}{dt} = 1$

(b) $\dfrac{dA}{dt} = 2$ and $\dfrac{dB}{dt} = -1$

(c) $\dfrac{dA}{dt} = -2$ and $\dfrac{dB}{dt} = -1$

(d) $\dfrac{dA}{dt} = 2$ and $\dfrac{dB}{dt} = 1$

Relating the Rates

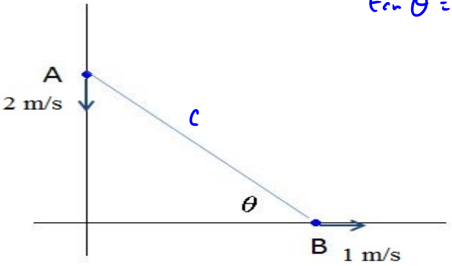
The pedestrians' positions and the intersection form a right triangle. So θ, A, and B are related by the equation

$$\tan\theta = \frac{A}{B}$$

Question: Use implicit differentiation to find an expression relating $\frac{d\theta}{dt}$ to the rates of A and B.

$\sin\theta = \frac{A}{c}$, $\cos\theta = \frac{B}{c}$,

$\tan\theta = \frac{A}{B}$



Question $\tan\theta = \frac{A}{B}$

The relation between the rates is given by

$$\frac{d}{dt}\tan\theta = \frac{d}{dt}\left(\frac{A}{B}\right)$$

$$\left(\sec^2\theta\right)\cdot\frac{d\theta}{dt} = \frac{\frac{dA}{dt}B - A\frac{dB}{dt}}{B^2}$$

(a) $\dfrac{d\theta}{dt} = \dfrac{\frac{dA}{dt}B - A\frac{dB}{dt}}{B^2}$

(b) $\sec^2\left(\dfrac{d\theta}{dt}\right) = \dfrac{\frac{dA}{dt}}{\frac{dB}{dt}}$

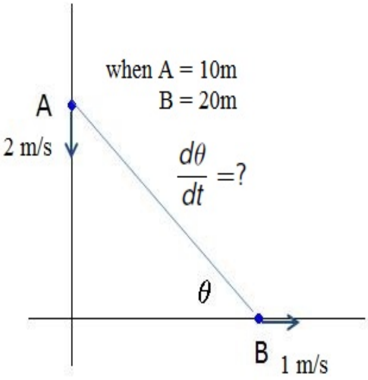
(c) $\sec^2(\theta)\dfrac{d\theta}{dt} = \dfrac{\frac{dA}{dt}B - A\frac{dB}{dt}}{B^2}$

(d) $\sec^2(\theta)\dfrac{d\theta}{dt} = \dfrac{A}{B}\dfrac{dA}{dt} + \dfrac{A}{B}\dfrac{dB}{dt}$

The Final Result

Determine the rate at which the angle θ shown in the diagram is changing when A is 10m from the intersection and B is 20 m from the intersection?

$$\sec^2\theta \, \frac{d\theta}{dt} = \frac{\frac{dA}{dt}B - A\frac{dB}{dt}}{B^2}$$

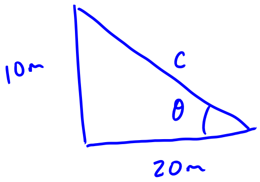


$$\frac{d\theta}{dt} = \frac{\frac{dA}{dt}B - A\frac{dB}{dt}}{B^2} \cdot \frac{1}{\sec^2\theta}$$

$$\frac{d\theta}{dt} = \frac{\frac{dA}{dt}B - A\frac{dB}{dt}}{B^2} \cos^2\theta$$

we'll need $\cos\theta$

when $A=10$ and $B=20$



$c^2 = A^2 + B^2 = 10^2 + 20^2 = 100 + 400 = 500$

$c = \sqrt{500} = 10\sqrt{5}$

At this time $\cos\theta = \frac{20}{10\sqrt{5}} = \frac{2}{\sqrt{5}}$

$$\frac{d\theta}{dt} = \frac{\left(-2\,\frac{m}{sec}\right)20m - (1\,m/sec)(10m)}{(20m)^2} \cdot \left(\frac{2}{\sqrt{5}}\right)^2$$

$$= \frac{(-40 - 10)\,\frac{m^2}{sec}}{400\,m^2} \cdot \frac{4}{5}$$

$$\frac{d\theta}{dt} = \frac{-50}{400} \cdot \frac{4}{5} \cdot \frac{1}{\text{sec}}$$

$$= \frac{-1}{10} \frac{1}{\text{sec}}$$

The angle is decreasing at a rate of $\frac{1}{10}$ th radian per second.

Section 4.7: Optimization

Optimization problems arise in every field of study and every industry.

- minimize cost and maximize revenue,
- maximize crop yield,
- minimize driving time,
- maximize volume,
- minimize energy

Often, some constraint (extra condition) must simultaneously be satisfied.

Applied Optimization Example

we're constrained by this requirement on area

A 216 m^2 rectangular pea patch is to be enclosed by a fence and divided into two equal parts by another fence parallel to one of its sides. What dimensions of the outer rectangle will require the smallest total length of fencing and how much fencing will be needed?

we want to minimize the length of fence

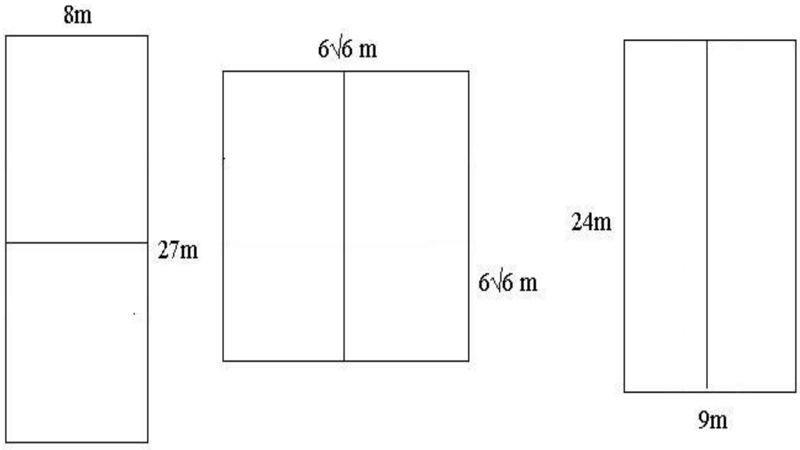
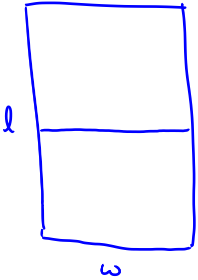


Figure: Different pea patch configuration that all enclose $216m^2$.

We start with a representative rectangle.



Let ℓ and w be the length and width of our pea patch in meters.

The area $A = \ell w$, and the total lenth of fencing $F = 3w + 2\ell$.

Our question: What is the minimum value of F given $A = 216\ m^2$? And what are the corresponding length and width?

Since $A = lw = 216$, l and w are not really independent variables. We can write F as a function of l alone by noting

$$lw = 216 \implies w = \frac{216}{l}$$

So $F = 3w + 2l = 3\left(\frac{216}{l}\right) + 2l$

Now we want to minimize

$$F(l) = \frac{648}{l} + 2l = 648\,l^{-1} + 2l$$

Let's find and classify critical numbers.

$$F'(\ell) = -648\,\ell^{-2} + 2 = \frac{-648}{\ell^2} + 2$$

$F'(\ell)$ is undefined if $\ell = 0$, but $\ell > 0$.

$$F'(\ell) = 0 \implies \frac{-648}{\ell^2} + 2 = 0 \implies 2 = \frac{648}{\ell^2}$$

$$\ell^2 = \frac{648}{2} = 324 \implies \ell = \sqrt{324} \quad \text{or} \quad \ell = -\sqrt{324}$$

Since $\ell > 0$, we have one critical number

$$\ell = \sqrt{324} = 18$$

Let's verify that $\ell = 18$ minimizes F.

Let's use the 2nd derivative test.

$$F'(\ell) = \frac{-648}{\ell^2} + 2 = -648\,\ell^{-2} + 2$$

$$F''(\ell) = (-2)(-648)\,\ell^{-3} + 0 = 2(648)\,\ell^{-3}$$

$$= \frac{2(648)}{\ell^3}$$

$$F''(18) = \frac{2(648)}{(18)^3} > 0$$

F is concave up @ $\ell = 18$

F is minimized when $l = 18$ m.

From $w = \frac{216}{l}$, we set $w = \frac{216}{18} = 12$

The dimensions should be 12 m $\times$ 18 m

with the extra piece parallel to the

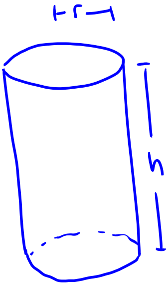
12 m side.

Let's Do One Together

constraint on volume

A can in the shape of a right circular cylinder is to have a volume of 128π cubic cm. The material that the top and bottom are made of costs \$0.20/cm^2 and the material that the lateral surface is made of costs \$0.10/cm^2. Find the dimensions of the can that minimize the total cost of production.

want minimum cost

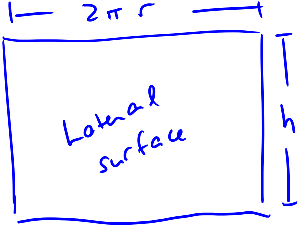


There are 2 dimensions, radius and height.

Let r and h be the radius and height in cm.

The top and bottom have area

$$A_c = \pi r^2$$



The area of the lateral surface

$$A_L = 2\pi r h$$

we'll have two disks $A_c = \pi r^2$

and one rectangle $A_L = 2\pi r h$

Question

The total cost $C =$ (cost of lateral surface) + (cost of top & bottom). The cost for the lateral surface was \$0.10/cm^2 while the cost for the top and bottom material is \$0.20/cm^2. The surface area was $S = 2\pi rh + 2\pi r^2$. Which of the following is the cost function?

(a) $C = 2\pi rh + 2\pi r^2$

(b) $C = 0.1(2\pi rh) + 0.2(2\pi r^2)$

(c) $C = 0.2(2\pi rh) + 0.1(2\pi r^2)$

(d) $C = (0.1)(0.2)(2\pi rh + 2\pi r^2)$

Question

The cost appears as a function of two variables, r and h. But we need it to be a function of only one variable.

The volume of the can $V = \pi r^2 h$. We are told it must hold 128π cm^3. Which of the following could be used to express C as a function of r alone?

(a) $h = \dfrac{128}{r}$

(b) $r = \dfrac{128}{\sqrt{h}}$

(c) $h = \dfrac{128}{r^2}$

Question

We can write the cost function in terms of r as

$$C = \frac{25.6\pi}{r} + 0.4\pi r^2$$

Which of the following is the derivative of C with respect to r?

(a) $\dfrac{dC}{dr} = \dfrac{-25.6\pi}{r^2} + 0.8\pi r$

(b) $\dfrac{dC}{dr} = \dfrac{-25.6\pi + 0.8\pi r}{r^2}$

(c) $\dfrac{dC}{dr} = \dfrac{-25.6\pi}{r^2} + 0.4\pi r$

Question

$$\text{Given that} \quad \frac{dC}{dr} = \frac{-25.6\pi}{r^2} + 0.8\pi r,$$

The critical number(s) of C are

(a) 0 and 32

(b) 0 and $\sqrt[3]{32}$

(c) can't be determined without more information

(d) $\sqrt[3]{32}$

Question

We suspect that the optimal size for the radius, the one that minimizes cost is $\sqrt[3]{32}$. We decide to use the second derivative test to check. We find that

$$\frac{d^2C}{dr^2} = \frac{d}{dr}\left(\frac{-25.6\pi}{r^2} + 0.8\pi r\right) = \frac{51.2\pi}{r^3} + 0.8\pi$$

With no computation, we determine that $r = \sqrt[3]{32}$ is a local minimum because

(a) $C''(r)$ is positive for all positive r, so the graph is concave up.

(b) $C''(r)$ is negative for all positive r, so the graph is concave up.

(c) $C''(r)$ is positive for all positive r, so the graph is concave down.

(d) $C''(r)$ is negative for all positive r, so the graph is concave down.

Question

Since the optimal $r = \sqrt[3]{32}$ and $h = 128/r^2$ our recommendation for minimizing the cost is a can with dimensions

(a) radius of $\sqrt[3]{32}$ cm and height $128/\sqrt[3]{32}$ cm

(b) radius of $\sqrt[3]{32}$ cm and height $128/\sqrt[3]{32^2}$ cm

(c) radius of $\sqrt[3]{32}$ cm and height 4 cm