

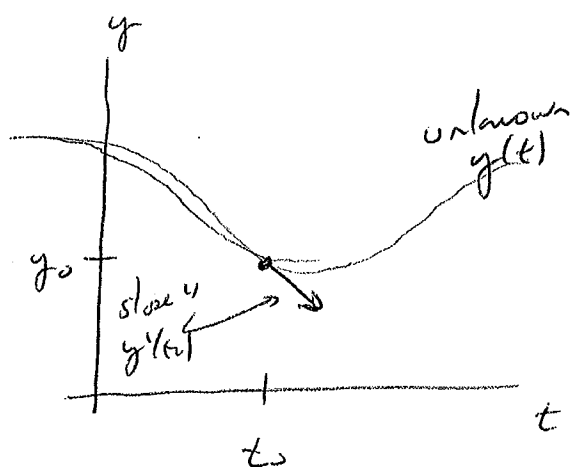
Q1: In the absence of analytic tools, how can we "see" a soln to an IVP?

Q2: How do computers "solve" ODEs?

Model:

$$\frac{dy}{dt} = f(t, y), \quad y(t_0) = y_0$$

where both f, f_y are cont "around" $(t_0, y_0) \in \mathbb{R}^2$.



- Near (t_0, y_0) solns are unique.
- Slope field about at (t_0, y_0) gives us $y'(t)$ for solution $y(t)$ that satisfies $y(t_0) = y_0$.
- eqn of line tangent to $y(t)$ at (t_0, y_0) is

$$y - y_0 = y'(t_0)(t - t_0) \quad \text{or} \quad y = y_0 + y'(t_0)(t - t_0).$$

like in Calc I, if we keep t close to t_0 , then this tangent line is a "good" approx to the actual solution, $y(t)$.

Idea: ① Follow tangent line for a short time:

~~Let~~ ^{Let} $t_1 = t_0 + h$ for small h .

Then $y_1 = y_0 + y'(t_0)(t_1 - t_0)$ (call this line l_0)
 $= y_0 + f(t_0, y_0)h$

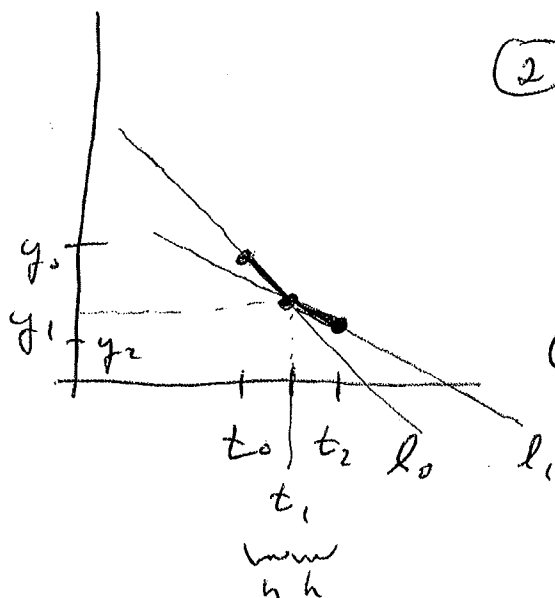
② Call the short line segment on l_0 from (t_0, y_0) to (t_1, y_1) your approximated soln.

③ Take (t_1, y_1) as your new starting pt and repeat ① and ② to generate (t_2, y_2) :

$$t_2 = t_1 + h$$

$$y_2 = y_1 + \underbrace{f(t_1, y_1)}_{y'(t_1)} h$$

for the different soln passing thru (t_1, y_1)



Notes ② Doing this for a small range of times will not produce a solution, but will produce something "near" the actual solution passing thru (t_0, y_0)

⑤ The amount one is "off" one time is called error, and is measurable.

⑥ This kind of computation is tailor made for computers

Euler Method

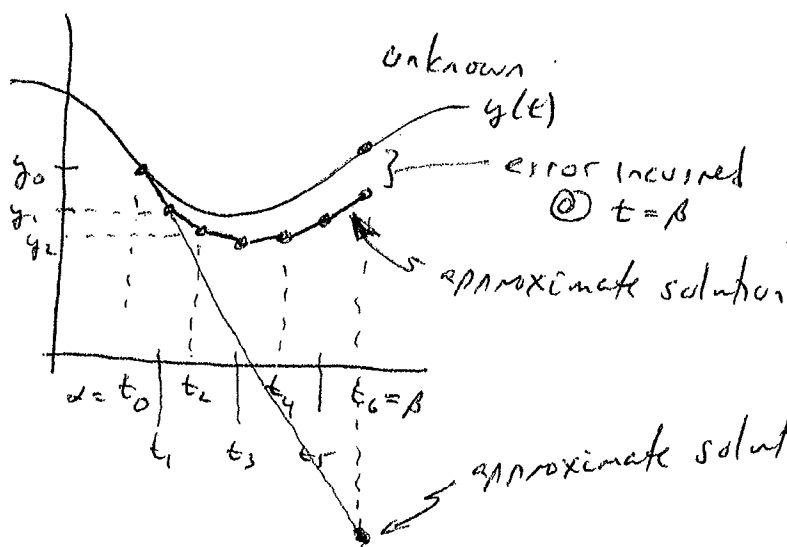
Given $y' = f(t, y)$, $y(t_0) = y_0$, with unique solutions,
one can approx. $y(t)$ on $[a, b]$, where $t_0 = a$ by

(I) Partition $[a, b]$ via step size h :

$$a = t_0, t_1, \dots, t_{n-1}, t_n = b, \quad t_i - t_{i-1} = h$$

(II) Evaluate $y_{i+1} = y_i + h \cdot f(t_i, y_i)$

(III) Connect pts (t_i, y_i) by straight lines.

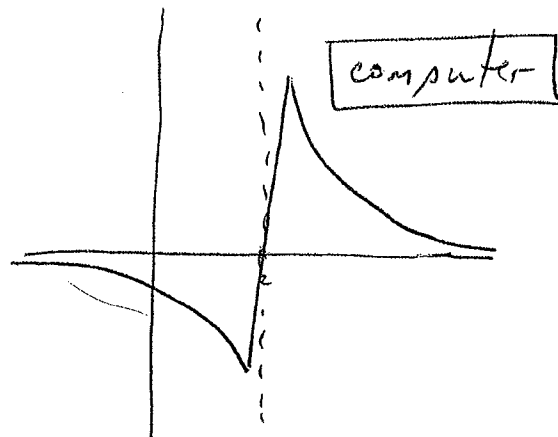
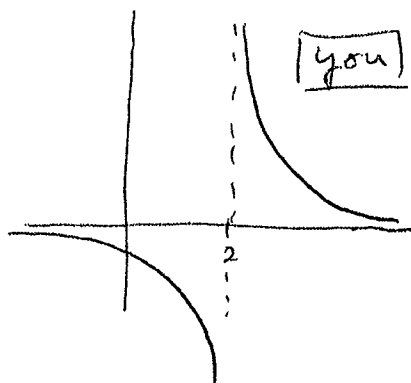


Q: What are the issues of the Euler Method?

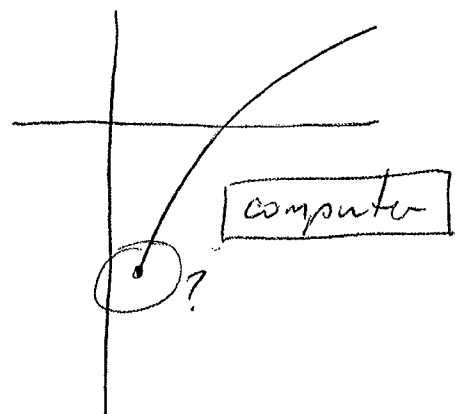
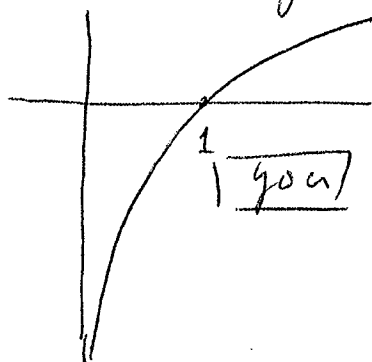
- ① If step size is too large, approximate solution is far away from real one.
- ② If step size is too small, computation is expensive
- ③ Computers cannot think (yet)....

- Computers cannot "see" asymptotes:

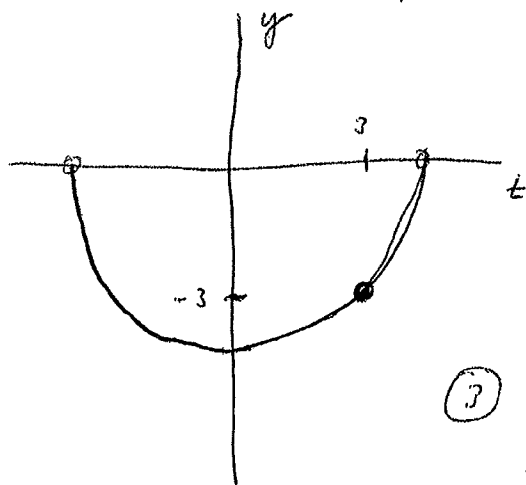
ex. Graph $f(x) = \frac{1}{x-2}$



ex. Graph $y = \ln x$



ex. Draw phase portrait of $y' = -\frac{x}{y}$. $y(3) = -3$.



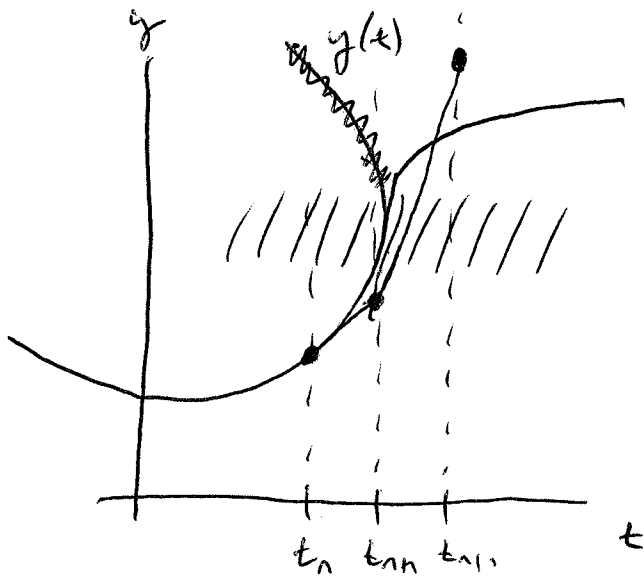
① what is y -intercept?

② Find t where $y(t) = 1$
(There are 2 of them).

③ See JODE phase portraits of this solution for different solution methods.

④ Near where the vector field is very steep,
(almost vertical), strange things can happen

This is because the step size horizontally may be
small, but vertically may be great!



See JODE.

How to generalize the Euler Method

Euler Method $y_{n+1} = y_n + h \cdot f(t_n, y_n)$

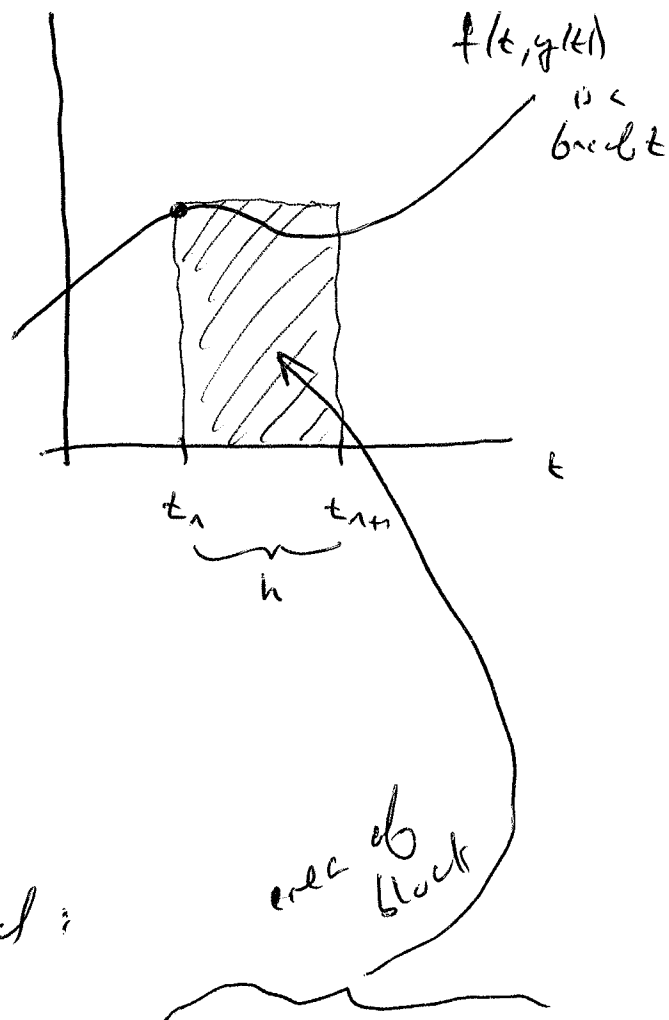
Integrating $f(t, y(t))$ over the interval $[t_n, t_{n+1}]$ would give $y(t_{n+1})$ precisely, since $y' = f(t, y(t))$, and

$$y(t) = y(t_n) + \int_{t_n}^t f(s, y(s)) ds$$

By FTC.

Instead, we estimate the integral:

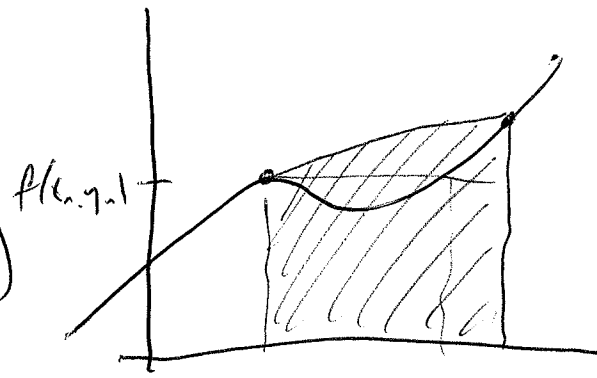
$$y(t_{n+1}) = y(t_n) + \int_{t_n}^{t_{n+1}} f(s, y(s)) ds \approx y(t_n) + f(t_n, y_n) \cdot \underbrace{(t_{n+1} - t_n)}_h$$



Improving the Euler Method involves only finding better estimates of the integral.

$$y_{n+1} = y_n + h \left(\frac{f(t_n, y_n) + f(t_{n+1}, y_{n+1})}{2} \right)$$

weird.

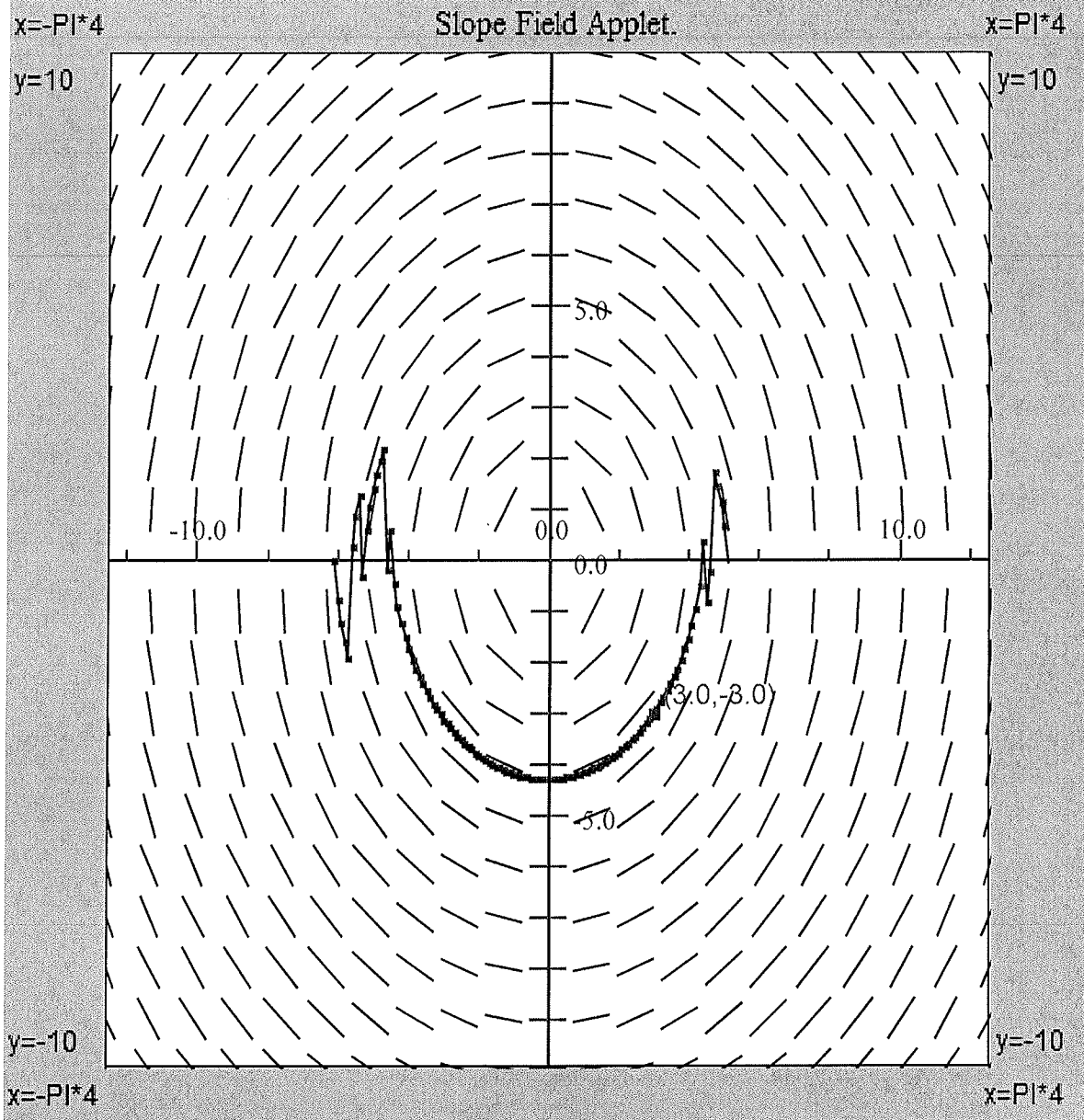


Trapezoidal Rule.

Instead, estimate y_{n+1} via standard Euler formula

$$y_{n+1} = y_n + \frac{1}{2}h \left(f(t_n, y_n) + f(t_{n+1}, \underbrace{y_n + hf(t_n, y_n)}_{\text{Euler formula estimate for } y_{n+1}}) \right)$$

The Runge-Kutta methods are simply better, more computationally expensive versions of this estimation process.



eqn #1: $dy/dx = -x/y$

Min. x $-\pi^4$

Max. x π^4

Min. y -10

Max. y 10

Num. of segs: x 20

y 20

Submit All

Show: ☒ Slop ☒ Solutid ☒ Lin ☒ Poi ☒ Ti ☒ Aj ☒ Init. Cor Euler

Step: 0.1

Add init. cond.: x 0.0

y 0.0

Submit

Show Table

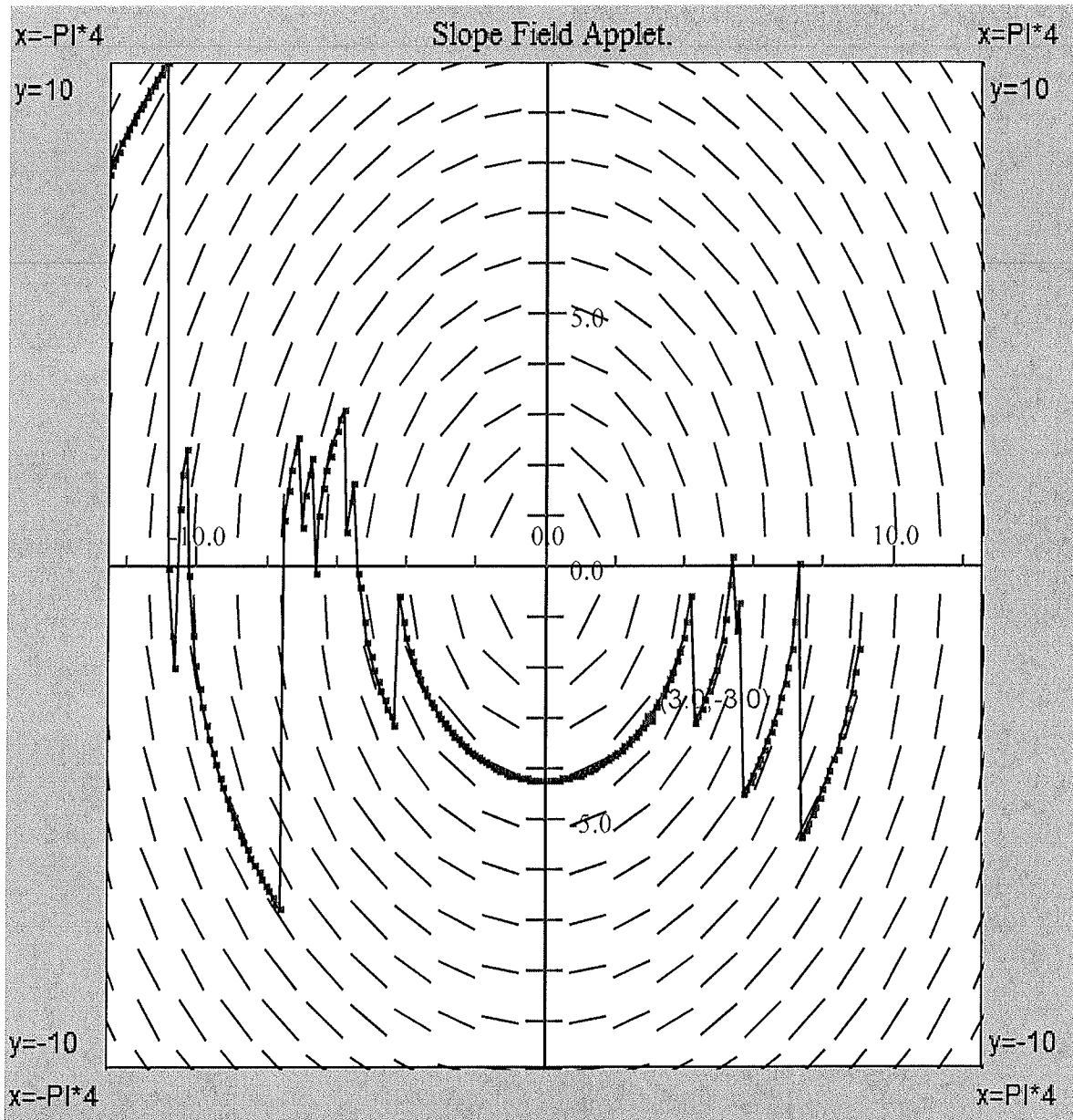
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eqn #1: $dy/dx = -x/y$

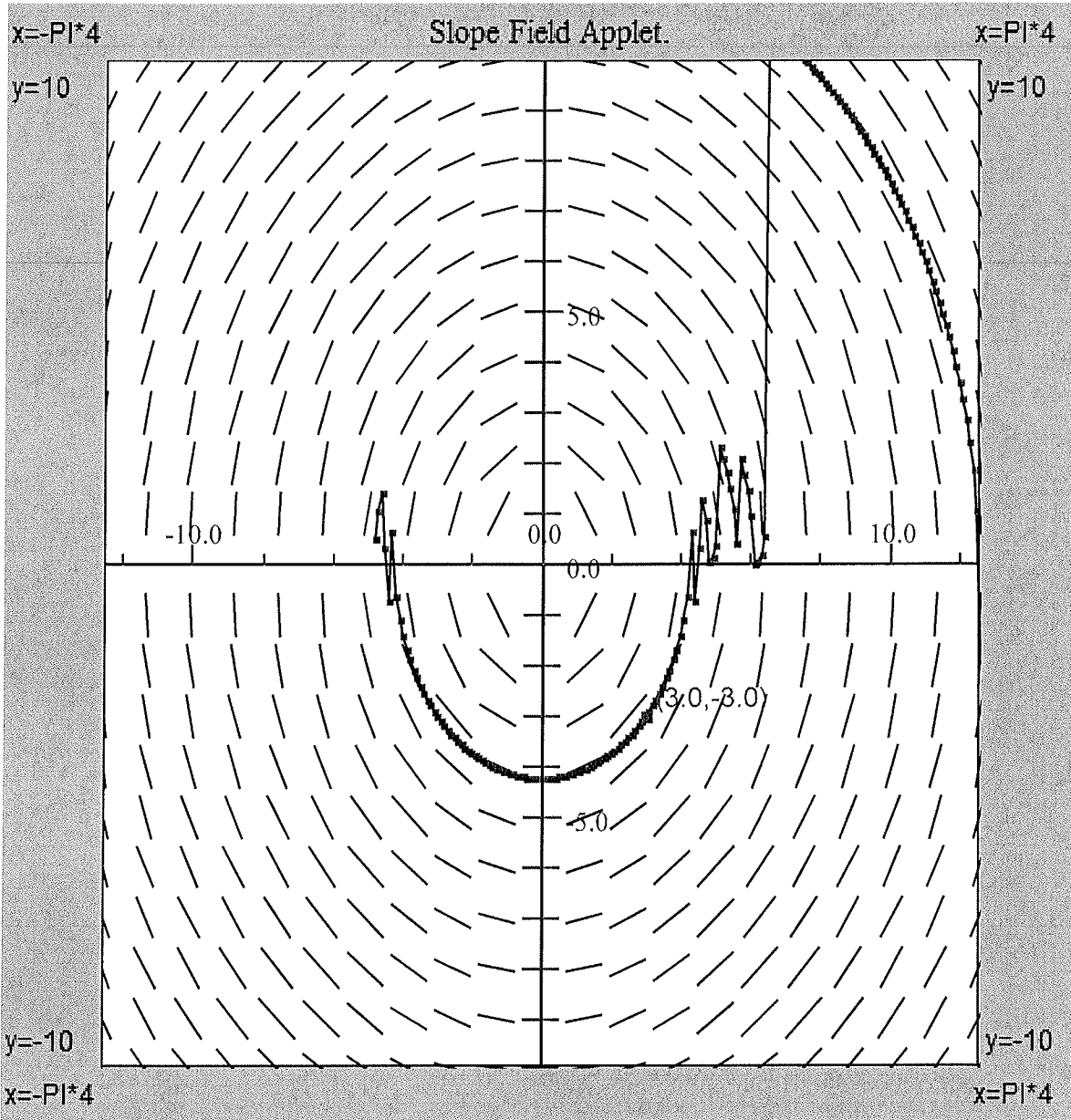
Min. x	$-\pi \cdot 4$	Max. x	$\pi \cdot 4$
Min. y	-10	Max. y	10

Num. of segs: x y

Show: ☒ Slope ☒ Solution ☒ Line ☒ Point ☒ Tick ☒ Axis ☒ Init. Cond. Mod. Eu

Add init. cond.: x y

Last error:



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Max. x $\pi \cdot 4$

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Max. y 10

Num. of segs: x 20

y 20

Submit All

Show: ☒ Slope ☒ Solution ☒ Line ☒ Point ☒ Title ☒ Axis ☒ Init. Cond. Midpoint ☐ Step: 0.1

Add init. cond.: x -12.0477584 y 8.85496183

Submit

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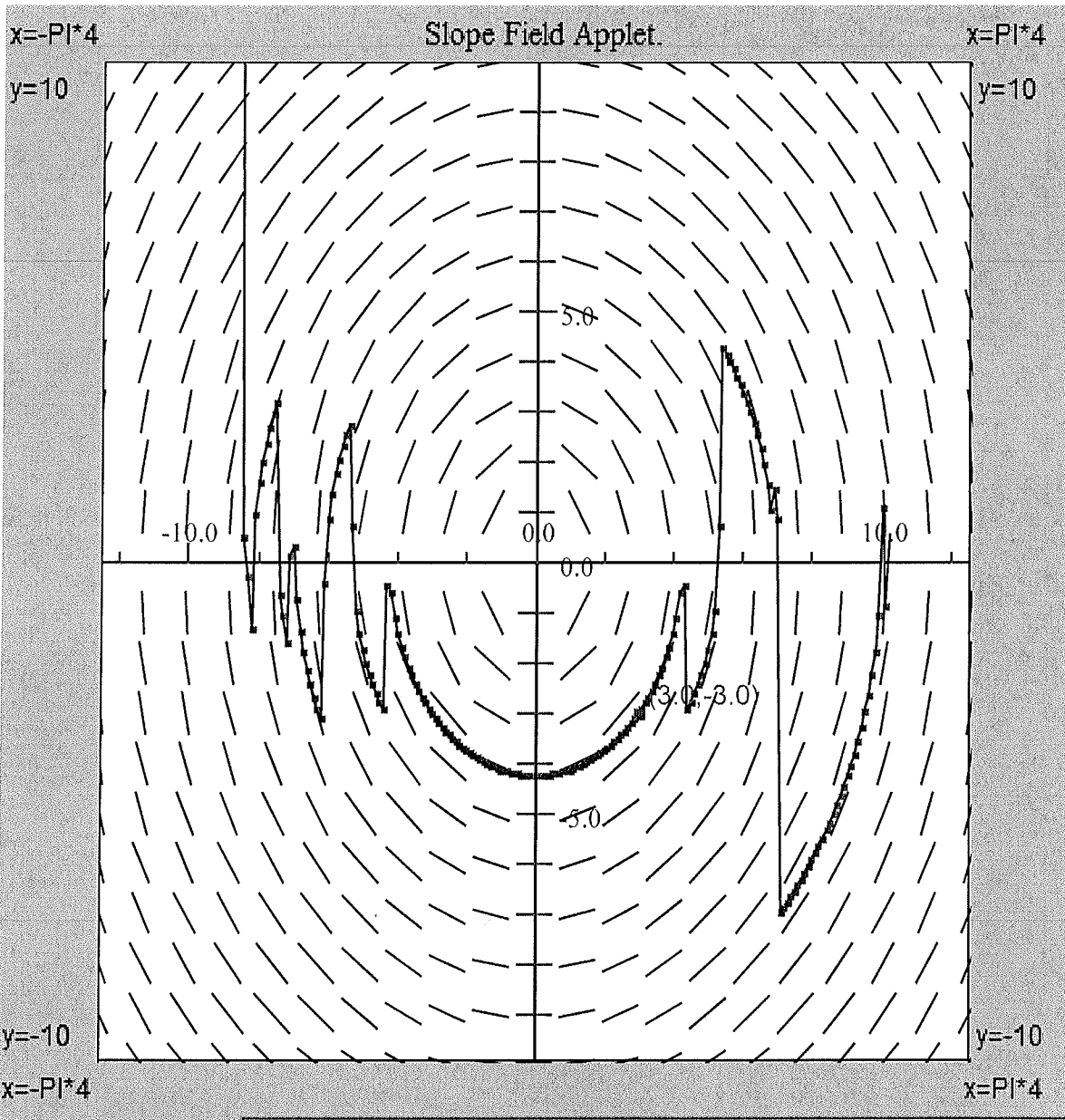
Clear All

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eqn #1: $\frac{dy}{dx} = -\frac{x}{y}$

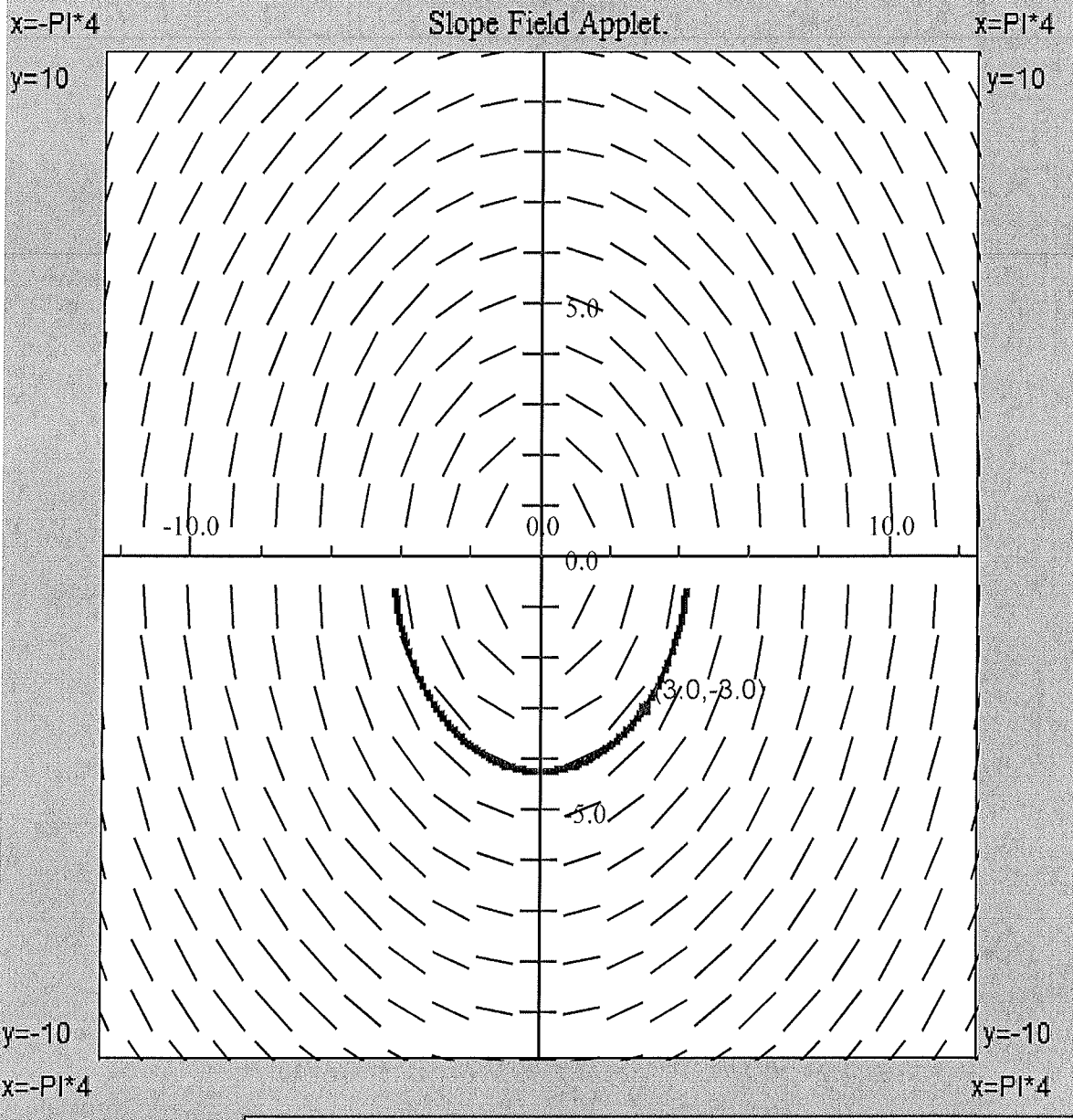
Min. x	$-\pi \cdot 4$	Max. x	$\pi \cdot 4$
Min. y	-10	Max. y	10

Num. of segs: x y

Show: ☒ Slope ☒ Solution ☒ Line ☒ Point ☒ Tick ☒ Axis ☒ Init. Con Step:

Add init. cond.: x y

Last error:



eqn #1: $dy/dx = -x/y$

Min. x	$-\pi \cdot 4$	Max. x	$\pi \cdot 4$
Min. y	-10	Max. y	10

Num. of segs: x 20 y 20 Submit All

Show: ☒ Slope ☒ Solution ☒ Line ☒ Point ☒ Tick ☒ Axis ☒ Init. Cond. RKF ▼ Step: 0.1

Add init. cond.: x -12.2472246 y 8.96946564 Submit Show Table Clear All

Last error: RKF algorithm: Minimal step reached: Show All Errors Print Frame