Math 307 Lecture 1

Introducing Differential Equations!

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Department of Mathematics
University of Washington

March 30, 2013

Today!

Plan for today:

- What is a differential equation?
- First order differential equations
- Separable and homogeneous equations

Next time:

- Linear equations
- Method: Integrating factors
- Method: Variation of parameters

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What's a Differential Equation?

Question

What is a differential equation?

Definition

A *differential equation* is mathematical expression describing a relationship between a function and its derivatives

Before going further we should think about:

- Examples of differential equations
- Why we care about differential equations
- The scope of our study of diff. equations in MATH 307

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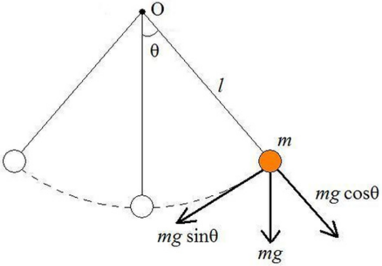
Example Diff. Eqn: Motion of a Rigid Pendulum

Figure : A physics-type picture you've probably seen before



- Newton's second law: $\tau = I\frac{d^2\theta}{dt^2}$
- Torque: $\tau = mgl\sin\theta$
- Moment of inertia: $I = ml^2$
- We get a differential equation!

$$\frac{d^2\theta}{dt^2} = \frac{mg}{l}\sin\theta$$

Example Diff. Eqn: Compound interest

Figure : A traditional celebration of compound interest as demonstrated by the notable entrepreneur Scrooge Mc. Duck

- For continuously compounded interest

$$\frac{dS}{dt} = rS$$

- S is invested capital
- r is interest rate
- This is a differential equation!
- Solution is $S(t) = S_0 e^{rt}$ (How do we get this?)

Example Diff. Eqn: Falling with air drag

Figure : Diving to the earth from the stratosphere is probably more fun than differential equations. Maybe?

- Newton's second law: $F = ma$
- Using a linear drag model

$$m\frac{d^2y}{dt^t} = -mg + k\frac{dy}{dt}$$

- y is your height
- g is gravitational acceleration
- k is a drag coefficient
- How can we solve this equation to get y?

Example Diff. Eqn: Fluid flow in one dimension

Figure : A fluid flow is as cool as it is complicated! Below is an example of what are called Von Karman vortices. Caveat: this flow is two-dimensional

- Goal: find velocity of the fluid $u = u(x, t)$
- x is position in the fluid
- t is time
- p is pressure
- ρ is density

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} = -\frac{1}{\rho}\frac{d^2 p}{dx^2}$$

- It's a *partial differential equation* because it has partial derivatives

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1. Introducing Differential Equations!
   - A First Look
   - Real-World Example Bonanza!
   - Scope of this Course
2. First Order Differential Equations
   - What's a First Order Equation?
   - Slope Fields
3. Separable and Homogeneous Equations
   - Separable Equations
   - Homogeneous Equations

The What and Why of MATH 307

Q: Why should we learn about differential equations?

A: As we have already seen, they naturally come up all over the place!

Q: So this course will make me a super-max-boss-pro-stud at everything to do with differential equations?

A: Unfortunately, it is impossible to learn everything in one quarter. Instead, we will focus on what are called first and second order equations.

Q: Ah, so at least I will be able to dominate these so-called first and second order equations?

A: Again no. Differential equations, even first and second order ones, can be really hard to solve! Our goal: learn to identify ones which are easy to solve and how

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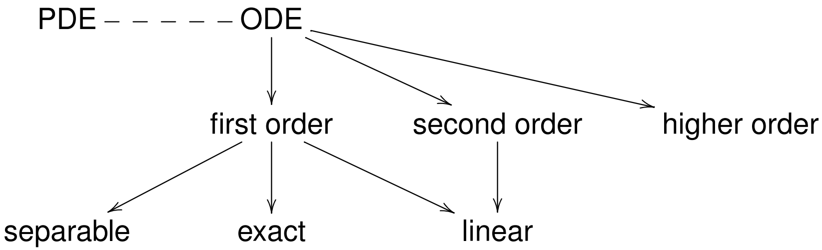
Classification of Differential Equations

Figure : A MATH 307 perspective of the "types" of differential equations



First Order Equations

Definition

A first order ordinary differential equation is an equation of the form

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

where f is a function of the two variables t and y.

- Our goal is to find *solutions* to first order differential equations
- Algebraically, this means find a function $y(t)$ satisfying the above equation
- Geometrically, this is finding a curve matching a slope field

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Slope Fields

- Consider the first order equation

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

- Make a "grid" of points in the x, y-plane
- At each grid point (x, y), draw a dash with slope $f(x, y)$
- This slope field "represents" our differential equation
- Solutions to the equation are curves whose tangent slopes agree with the dashes!
- Solution curves are determined uniquely by a point they contain (sometimes called an initial condition)

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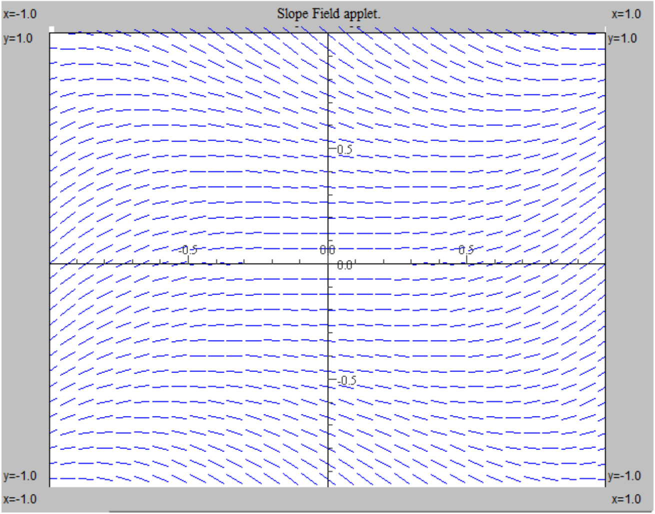
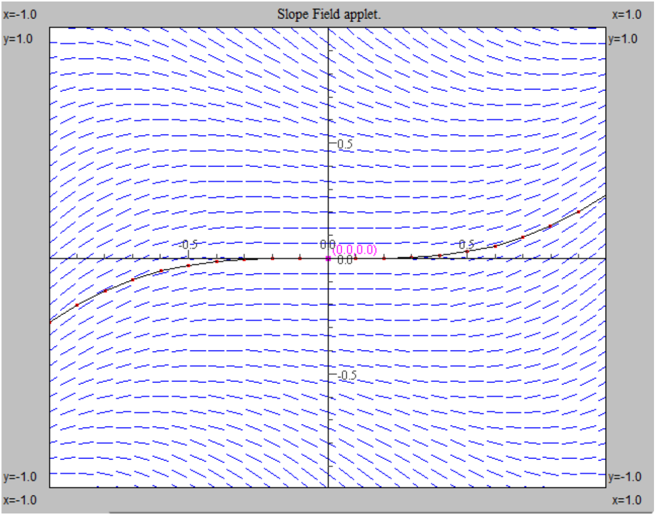
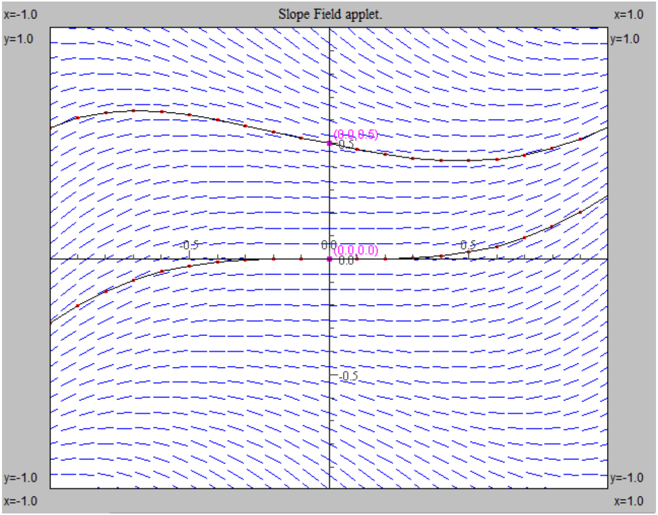
Slope Field Example: $\frac{dy}{dt} = x^2 - y^2$



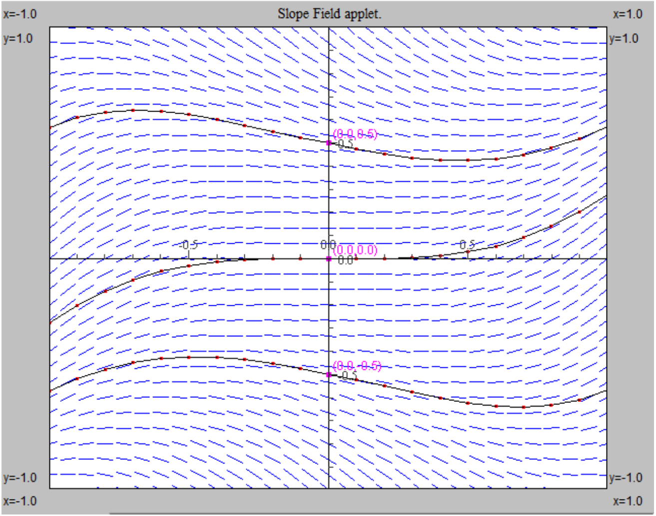
Slope Field Example: Solution satisfying $y(0) = 0$



Slope Field Example: Solution satisfying $y(0) = 0.5$



Slope Field Example: Solution satisfying $y(0) = -0.5$



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Separable Equation

Definition

A first order differential equation

$$\frac{dy}{dx} = f(x, y)$$

is called *separable* if $f(x, y) = g(x)h(y)$ for some functions g, h

Examples:

- $\frac{dy}{dx} = \frac{3x^2+4x+2}{2(y-1)}$
- $\frac{dy}{dx} = \frac{(y-3)\cos x}{1+2y^2}$
- $y' = (e^{-x} - e^x)/(3 + 4y)$
- $\sin(2x)dx + \cos(3y)dy = 0$

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Question

How can we solve a separable equation?

$$\frac{dy}{dx} = g(x)h(y)$$

$$\frac{1}{h(y)}dy = g(x)dx$$

$$\int \frac{1}{h(y)}dy = \int g(x)dx$$

... finish by solving for y

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Example

Find a solution to the differential equation $y' = (1 - 2x)y^2$ satisfying the initial condition $y(0) = -1/6$.

$$\frac{1}{y^2}y' = (1 - 2x)$$

$$\int \frac{1}{y^2}dy = \int (1 - 2x)dx$$

$$-\frac{1}{y} = x - x^2 + C$$

$$y = \frac{-1}{x - x^2 + C}$$

$y(0) = -1/6$ implies $C = 6$. Hence $y = \frac{-1}{x - x^2 + 6}$.

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Definition

A homogeneous equation is a first order differential equation of the form

$$\frac{dy}{dx} = f(x, y),$$

where $f(x, y) = g(y/x)$ for some function g.

- Homogeneous equations have "scale invariant" slope fields: if you zoom out, the slope field looks the same!
- Homogeneous equations are separable equations in disguise!

Examples:

- $\frac{dy}{dx} = \frac{x^2+xy+y^2}{x^2}$
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Solving Homogeneous Equations

Steps to solve:

- Do enough algebra to write $\frac{dy}{dx} = g(y/x)$
- Define a new variable $z = y/x$
- Since $xz = y$, implicit differentiation says

$$z + x\frac{dz}{dx} = \frac{dy}{dx}$$

- Plugging back into the original DE, we get a separable equation

$$z + x\frac{dz}{dx} = g(z)$$

- Solve ths separable equation for z and use $y = xz$ to WIN

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An Example Worked Out

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Find a solution to the differential equation $y' = \frac{x^2+xy+y^2}{x^2}$ satisfying the initial condition $y(1) = 0$.

- Notice that $y' = 1 + \frac{y}{x} + \frac{y^2}{x^2} = g(y/x)$ for $g(z) = 1 + z + z^2$
- If we set $z = y/x$, then we find $z + x\frac{dz}{dx} = 1 + z + z^2$

$$\frac{dz}{dx} = \frac{1+z^2}{x}$$

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An Example Worked Out ∼ Continued

$$\begin{aligned} \arctan(z) &= \ln|x| + C \\ z &= \tan(\ln|x| + C) \\ y &= xz = x\tan(\ln|x| + C) \end{aligned}$$

- Since $y(1) = 0$, we must have $0 = 1\tan(\ln|1| + C) = \tan(C)$.
- This tells us $C = 0$. Hence the solution we want is

$$y(x) = x\tan(\ln|x|)$$

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Summary!

What we did today:

- We learned what a differential equation is and why we should care
- We caught a glimpse of first order differential equations
- We learned how to solve separable and homogeneous equations

Plan for next time:

- Linear equations
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- We caught a glimpse of first order differential equations
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- Linear equations
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