# Motion Editing and Signal Processing

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# Motion Editing and Signal Processing

- Motion
  - What is motion really?
  - How do we represent it?
- Editing
  - How do we change it?
- Signal Processing
  - A science that provides a useful analytical framework and tools for motion

# Outline

*Goal: Basic Intuitions for Motion Editing*

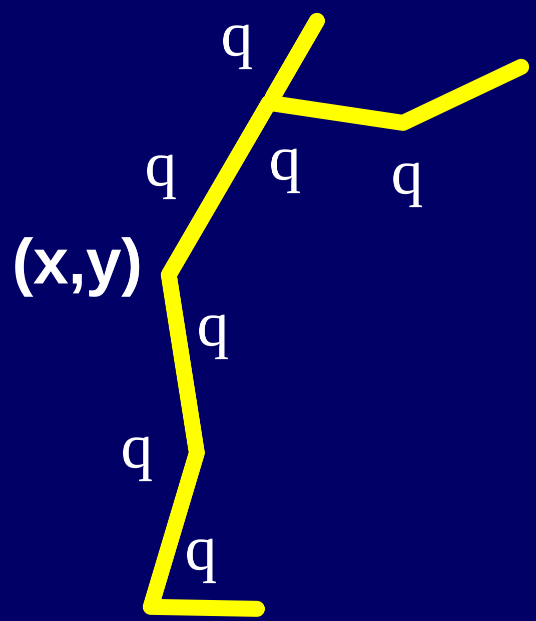
- "The" motion problem
- Properties in motions
- Signal processing basics
- Applications to motion editing
  - sampling and temporal control
  - filtering and other tools
  - adding, blending and warping

# What do we mean by motion?

- Animated Character
- Pose or Configuration
  - parameters in a vector

$$\mathbf{p} \in \Re^n$$

- Examples are articulated figures (humans)
  - trees of rigid links
  - center + joint angles
  - nothing specific about methods



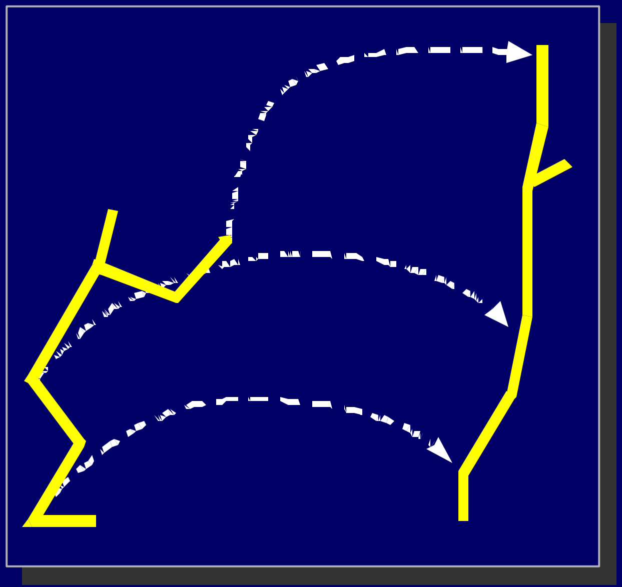

$\mathbf{p} = \{x, y, q_1, q_2, q_3, \ldots\}$

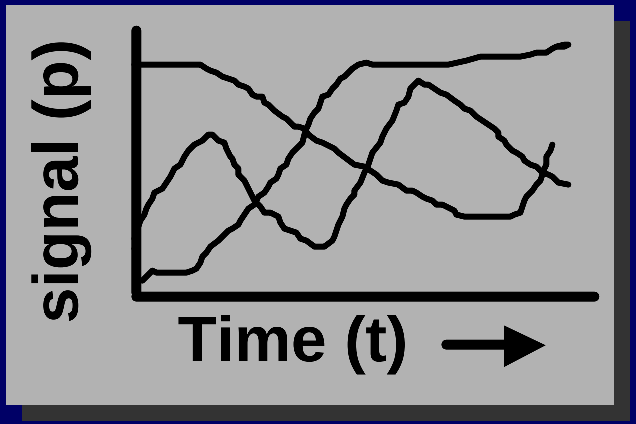
# What do we mean by motion? (2)

- A motion maps times to configurations

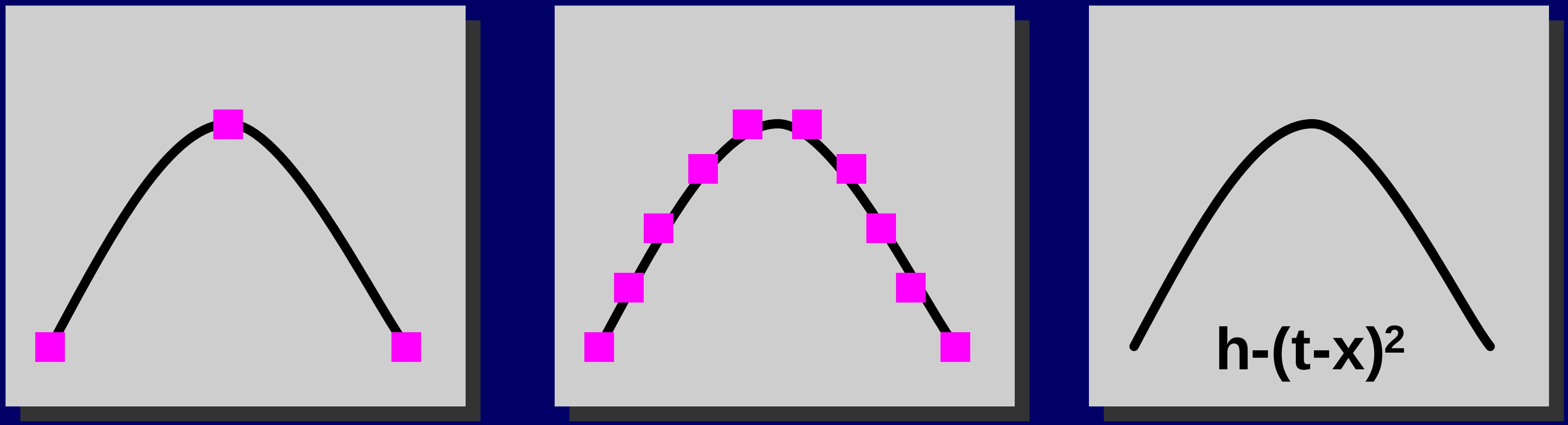
$$\mathbf{m}(t) \in \Re \Rightarrow \Re^n$$

- Vector-valued, time-varying signal
- Representation comes from creation
  - typically interpolation
  - may not be convenient for editing



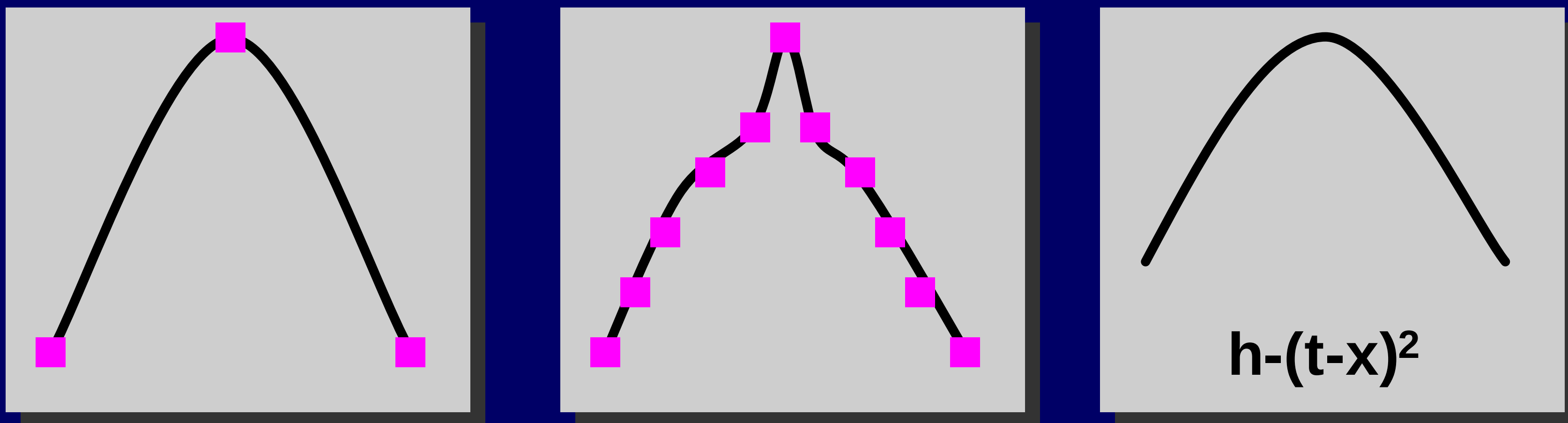


# Representation




- Many ways to represent a motion
- Different creation methods yield different representations
- Equivalent (in terms of output)

# Representation Matters




- **Different representations respond differently to change**
- **Different changes are convenient with different representations**

# From poses to motions...

- We have good tools for controlling what happens at a given instant (pose)
- Motions add another level of difficulty

- Lots of poses to change (tedious)
- Changes must be coordinated (hard)

- How to leverage our skill with poses?

# Properties of Motion

**What do we change? What do we preserve?**

**High Level Properties**

**Describe motion in abstract terms**

- Make it angrier!
- But keep the graceful dignity.

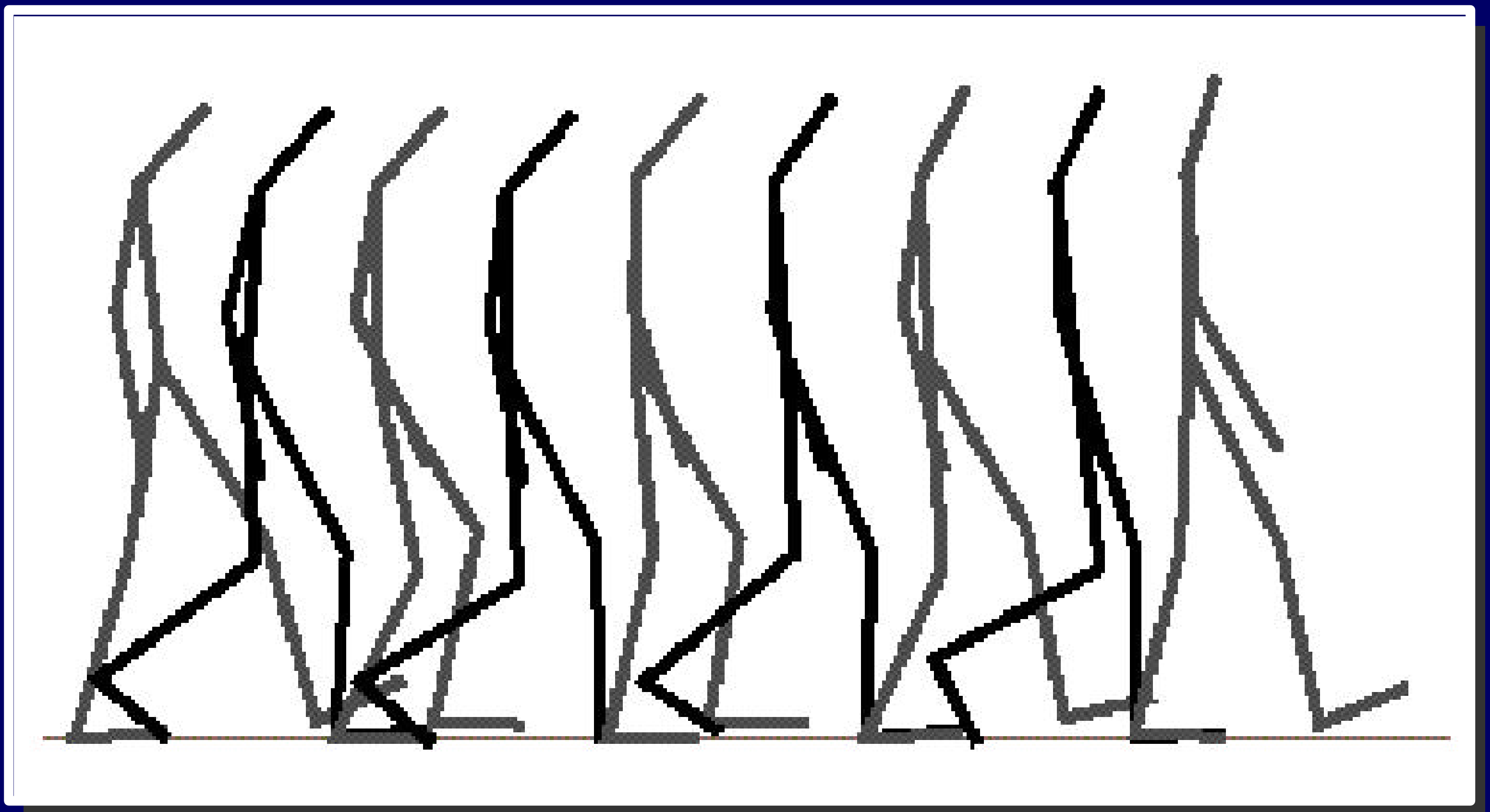
The art of motion editing is crossing this chasm.

**Low Level Properties**

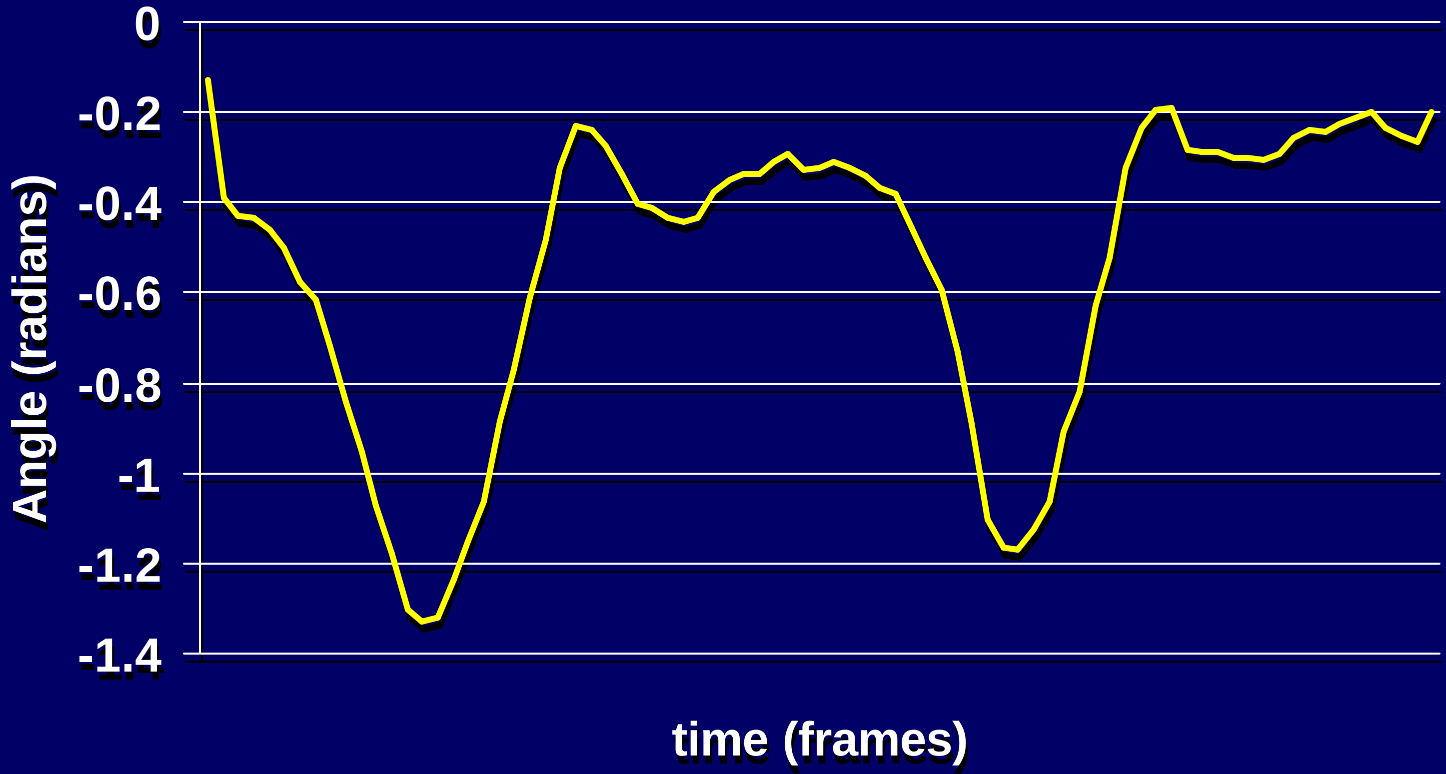
**Have to control small details**

- Poses, joint angles, timing, ...
- Not how we talk about motions.

# What makes *this* walk *this* walk?



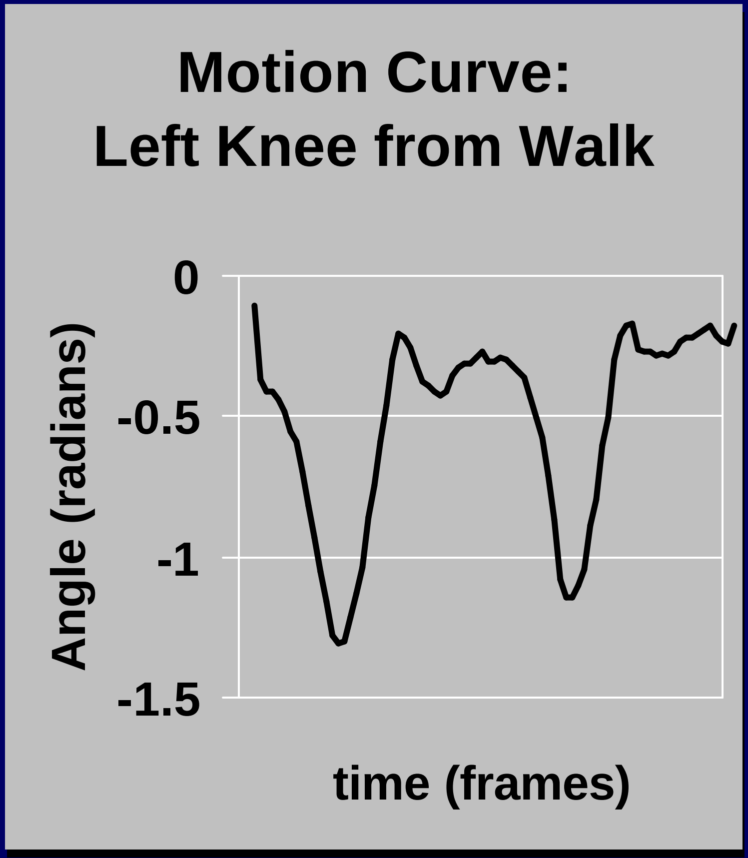
# Quiz: Name That Motion!



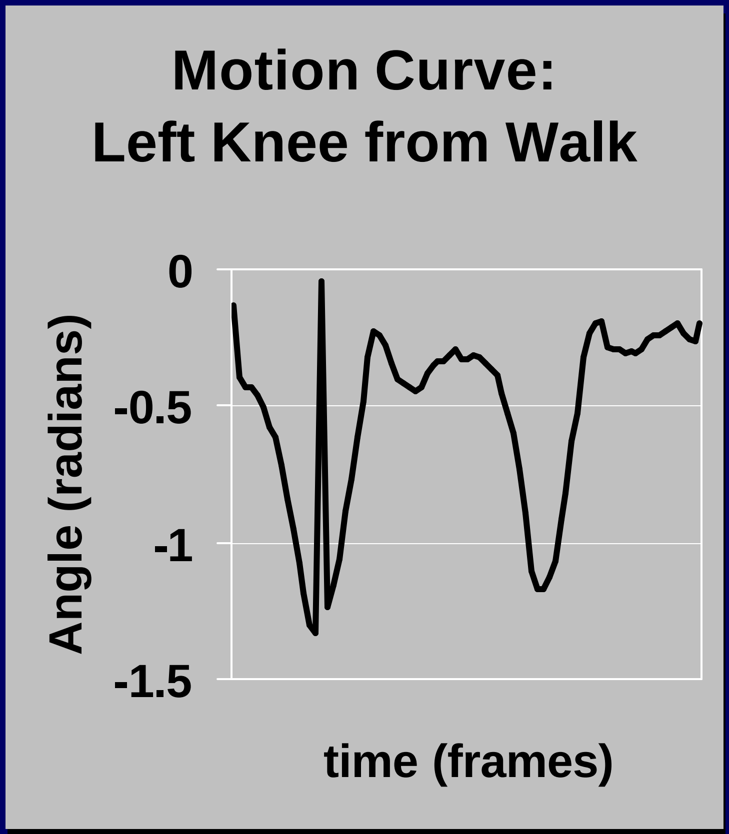
# A Motion Curve

- Where's the "Mike"?
- Where's the sad?
- Where's the walk?
- Where's the no skate?

How can we preserve (or alter) these properties if we can't see them?



# Easy to destroy motions

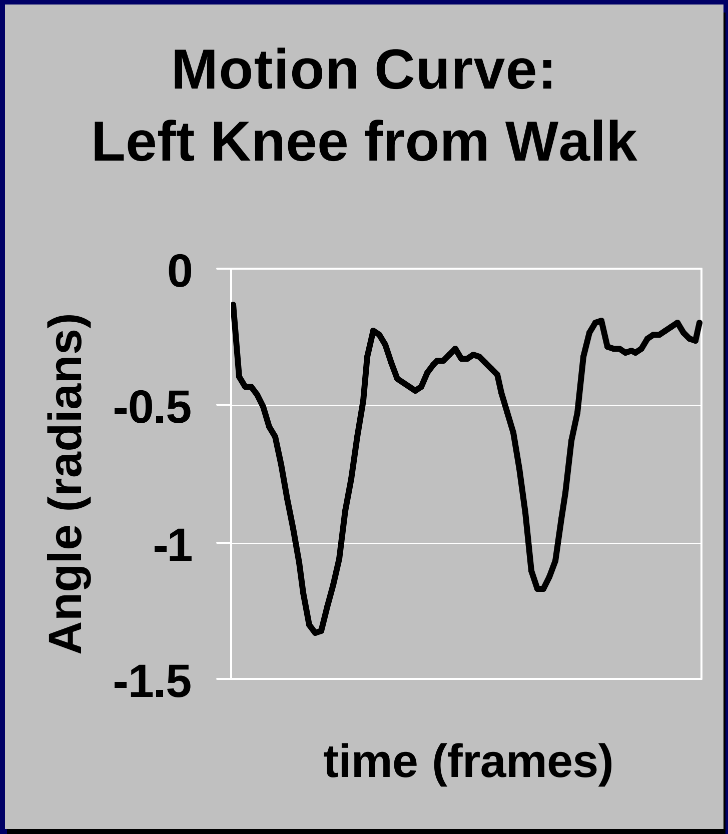



- Hard to identify properties
- Easy to destroy them

- How can we know what kinds of changes to make?

# Maybe we're looking the wrong way...

- **Spatial Analysis**
  - Need to consider several curves together
- **Temporal Analysis**
  - How things change
  - Frequency Domain Analysis
- **Signal Processing!**
  - A set of tools for looking at data



# Signal Processing Review

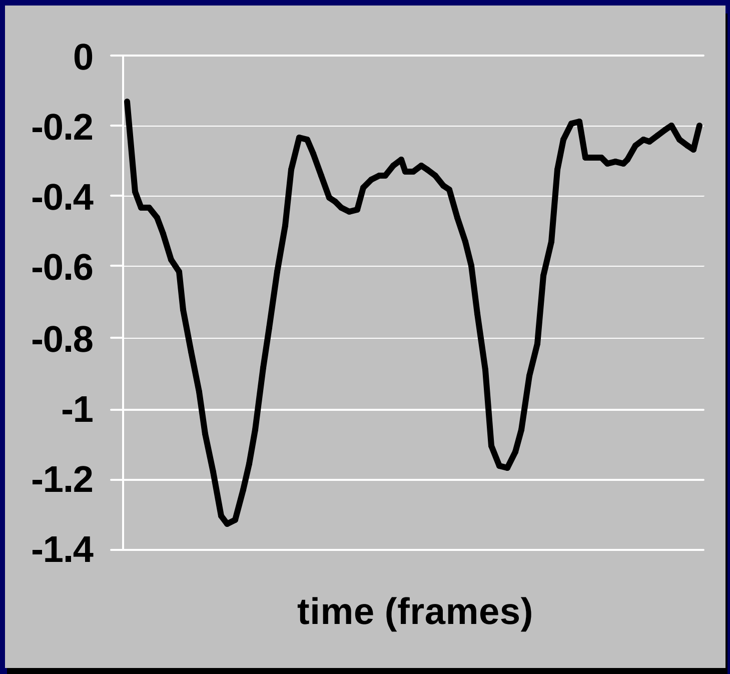
- A signal is a value that changes
  - Voltage, current, sound pressure, angles, ...
  - Something that carries information
- Signal theory doesn’t care what the value is

# Time Domain Analysis

- What is the value at a particular instant?

  v = f(t)

- Signal source is a black box
- This "view" lets us answer some questions easily




"Waveform" view

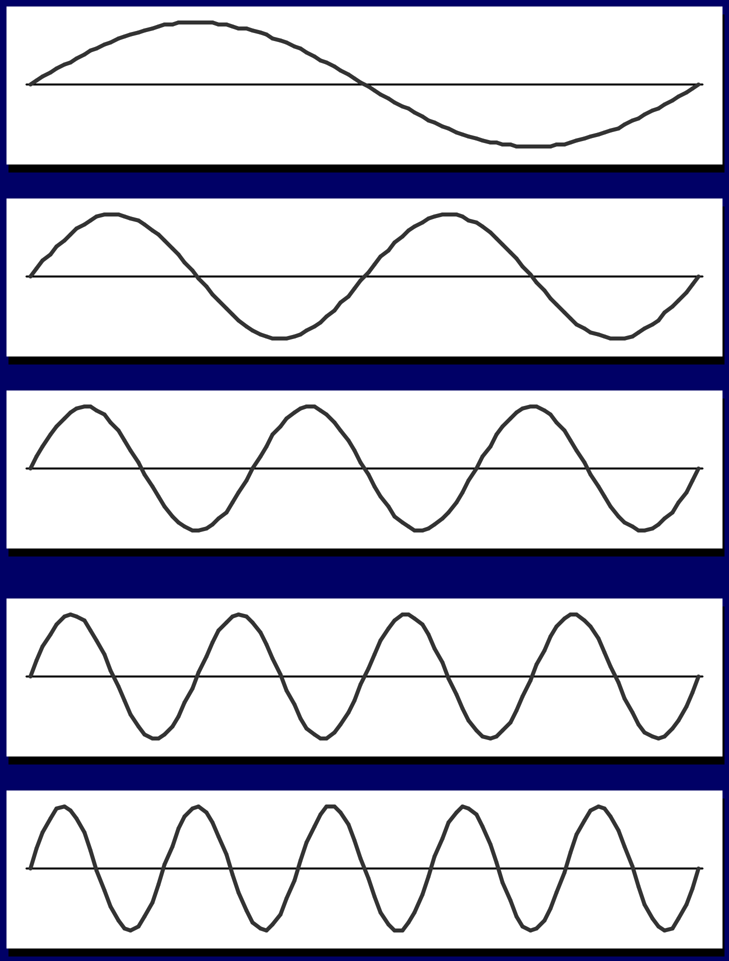
# Frequency Domain Analysis

- A different way to look at signals
- New representation, same information
- Different set of questions easy

- Decompose signals into simpler "building blocks"

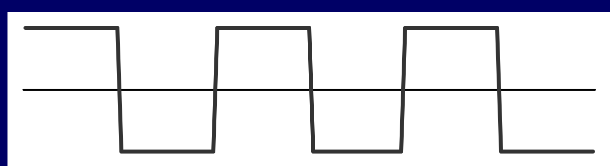
# Fourier Analysis

- Simple Form: Fourier Series
- Analyze periodic signals with sine waves
- More complex extensions for non-periodic signals



# Fourier Analysis

- **Decompose ANY periodic signal into sine signals (with some caveats)**



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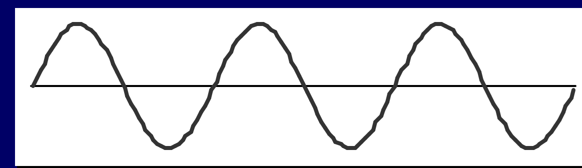

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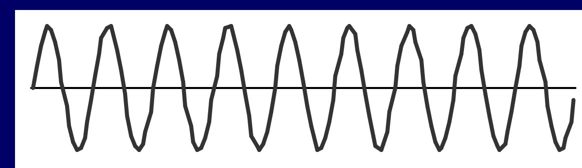
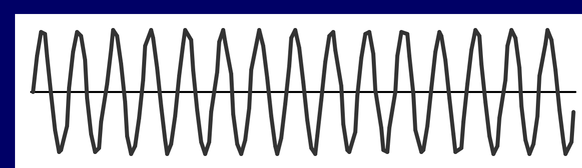
**1/3**



**+**

**1/5**



- **Possibly an infinite number of sine signals**

**+**

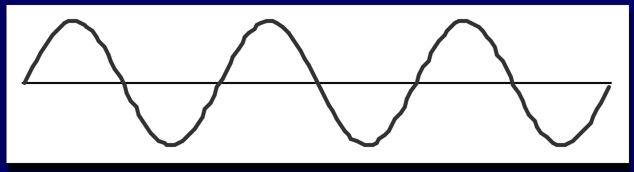
**1/7, 1/9, 1/11, 1/13, ▪▪▪**

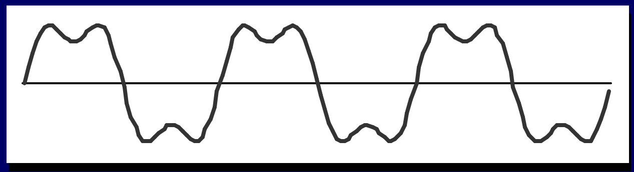
# Frequency Domain Representation

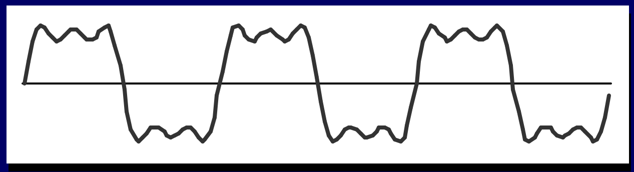
- Represent a signal by the amount of each “basis signal”
- A signal has high frequencies if its decomposition has these terms
- Allows us to see some general properties of the signal easily
- Fourier Transform converts between time and frequency representations
  - Inverse Fourier Transform converts back

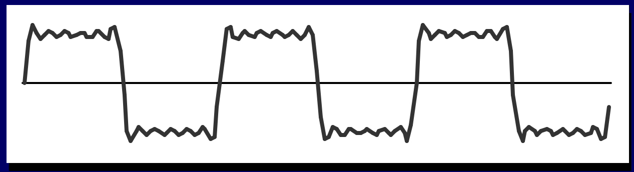
# Band-Limited Approximations

- Limited frequencies approximate signals
- More frequencies = better approximations
- Gives intuition for what high frequencies "mean"



# Intuitions of Frequency Analysis

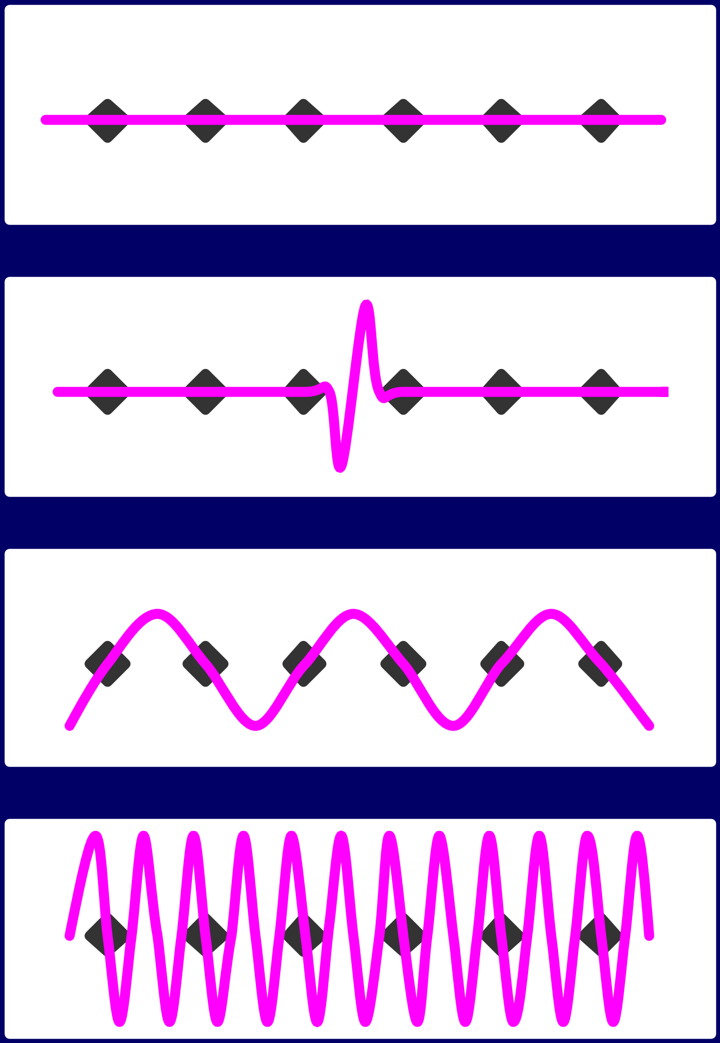
- Sharp edges require high frequencies to get good approximations
- "Smooth" signals = no high frequencies

Frequency Analysis says what kinds of things happen in a signal

Existence of properties, without specific details

# Sampling

- Sample the value of a signal at certain instants
- Can’t know what happened in between without additional information
- Frequency limit on signal insures we don’t miss anything



# What’s does this have to do with Motion Editing?

- A Motion is a signal
  - use the same tools as for everything else
- Vocabulary for discussing motions
  - frequency analysis
- Tools for manipulating signals
  - can be applied to our problems

# An Important Observation

- Frequency content is an important concept for motions
- High frequencies in a motion are a noticeable thing
  - Our perceptual system is tuned to them
  - Almost always have “meaning” impact, sudden moves, ...
- Care must be taken with high frequencies

# Motion is tough

## And it's not just motion capture's problem

### Motion Capture

Sample every frame

- No structure.
- No intent.
- lots of data!

Dense samples can represent rich frequency content

Noise, sensor errors

### Hand Animation

Data at Keyframes

- Structured?
- Remember why?
- Maybe lots of data.

Good animators create complex frequency content

Quality takes work

# Approach 1: Key Reduction

- Create “Keyframe” data from samples
- Find splines that fit through data
- Pro:
  - less data to deal with
  - use standard keyframe editing tools
- Con:
  - difficult to get exact fit, accuracy tradeoffs
  - doesn’t recreate structure

# Approach 2: Motion Signal Processing

- Apply signal processing techniques to motion
- The motion is just a signal after all
  - signal processing can be independent of representation
- Look to other fields for ideas of things to do to motions

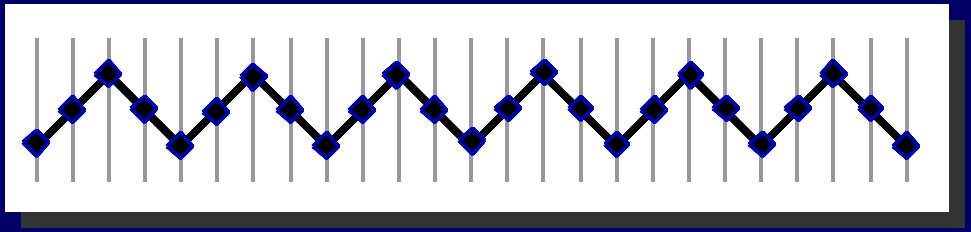
# Example 1: Time Manipulations

- Change time, not values
  v = m ( w(t) ) where w maps time->time
  - Notice - we don't say much about m
- Simple, obvious things to do
  - shift time
  - scale time
  - stretch time
  - warp time

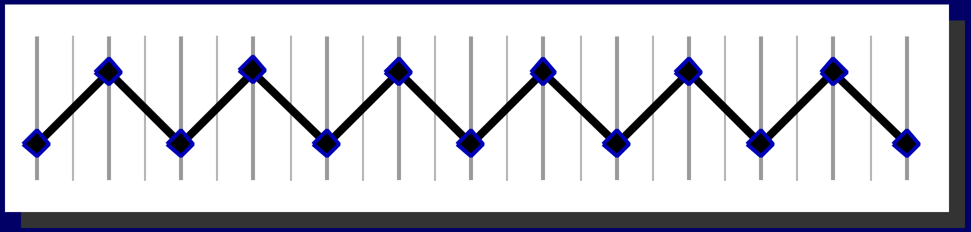
# Speeding Up a Motion

- Easy - just scale time: m(t) = m (2 * t)

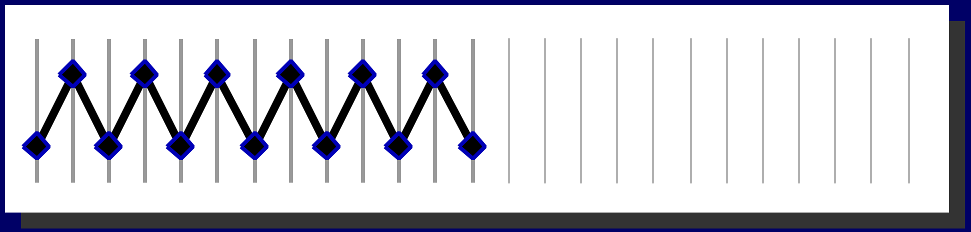
Start with a signal



Take every 2nd sample



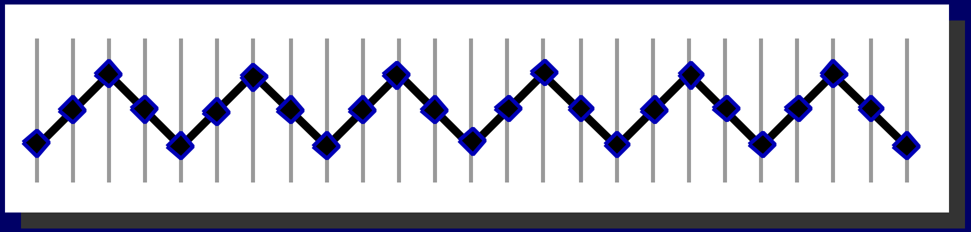
Now twice as fast!



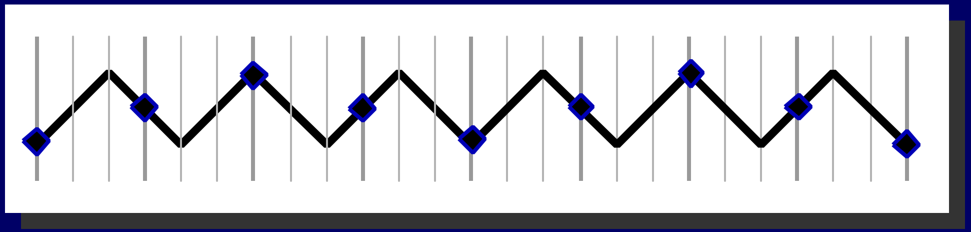
# Faster!

- That was easy! Let's try 3 times speed!

Start with a signal



Take every 3rd sample

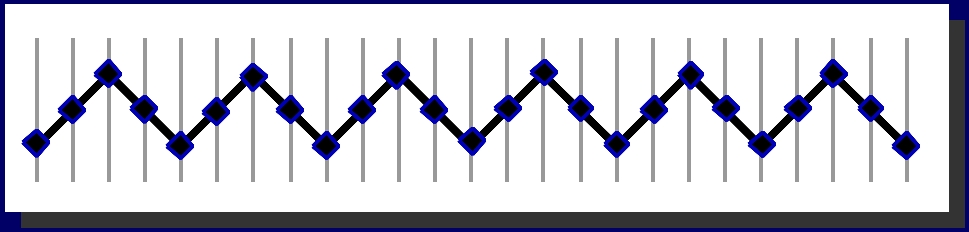


Now thrice as fast?

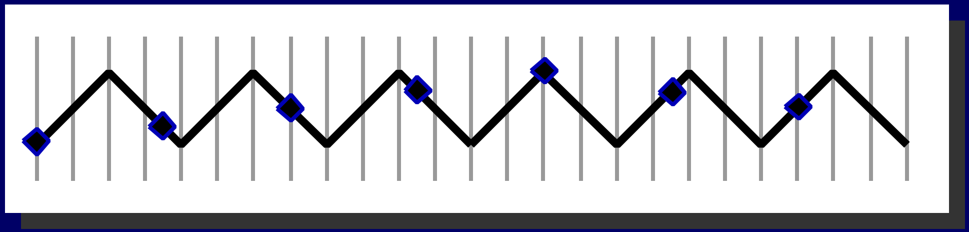
# Even Faster?

- Hmmm. How about 3 1/2 times speed?

Start with a signal



Take every 3.5 samples



This look slower!

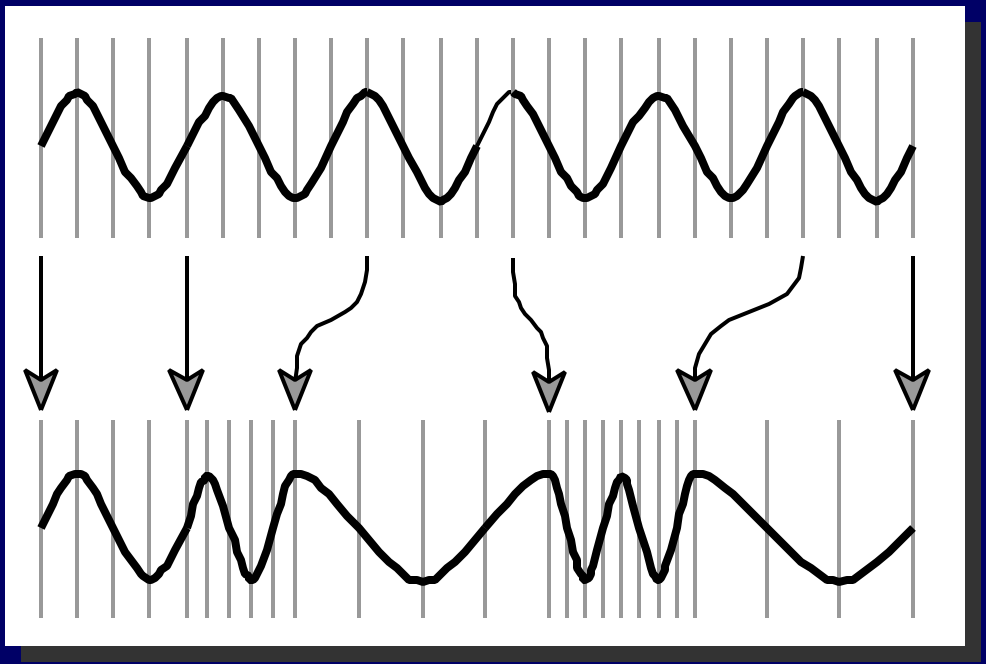
# Aliasing!

**Graphics 101 applies to motion editing!**

- Frequencies that are too high appear as lower frequencies
- Solution: pre-filter
  - make sure signal has no frequencies that are too high **before** sampling
- Signal processing tells us how to do resampling correctly

# Time Warping

- Interpolate corresponding time values
- Different regions scaled differently



# Example 2: Frequency Filtering

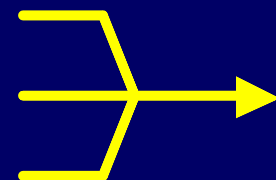
- Attenuate different frequencies
  - Low Pass: cut out high frequencies
  - Band Pass: allow a certain range through
  - High Pass: cut out low frequencies
- Ideal filters hard to implement
  - Real filters are far from ideal!
- Easy: linear filters
  - FIR: finite impulse response

# FIR Filters

- Take a weighted average of nearby samples
- Discrete Convolution
- The weights are called the "kernel"
- Choice of kernel determines function of filter

$$o(t) = k_0*i(t-1)+k_1*i(t)+k_2*i(t+1)$$

| in | out |
|---|---|
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 4 |
| 5 | 5 |
| 6 | 6 |
| 7 | 7 |

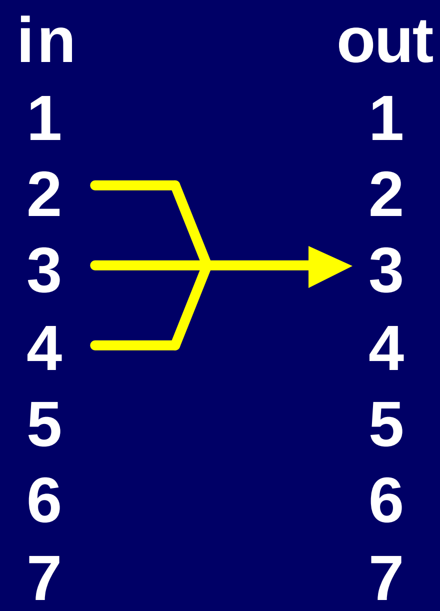


$$o(2) = k_0*i(1)+k_1*i(2)+k_2*i(3)$$

# FIR Filters

- Take a weighted average of nearby samples
- Discrete Convolution
- The weights are called the “kernel”
- Choice of kernel determines function of filter

$$o(t) = k_0*i(t-1)+k_1*i(t)+k_2*i(t+1)$$

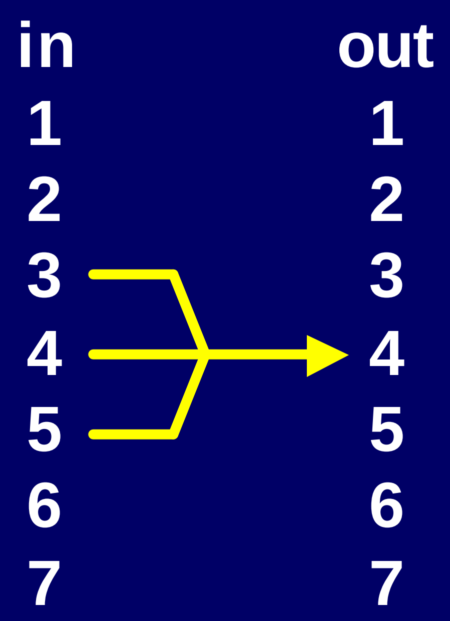



$$o(3) = k_0*i(2)+k_1*i(3)+k_2*i(4)$$

# FIR Filters

- Take a weighted average of nearby samples
- Discrete Convolution
- The weights are called the “kernel”
- Choice of kernel determines function of filter

$$o(t) = k_0*i(t-1)+k_1*i(t)+k_2*i(t+1)$$




$$o(4) = k_0*i(3)+k_1*i(4)+k_2*i(5)$$

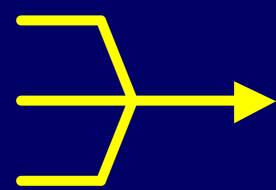
# FIR Filters

- Take a weighted average of nearby samples
- Discrete Convolution
- The weights are called the “kernel”

- Choice of kernel determines function of filter

$$o(t) = k_0*i(t-1)+k_1*i(t)+k_2*i(t+1)$$

| in | out |
|---|---|
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 4 |
| 5 | 5 |
| 6 | 6 |
| 7 | 7 |



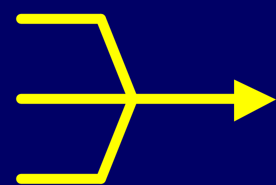
$$o(5) = k_0*i(4)+k_1*i(5)+k_2*i(6)$$

# FIR Filters

- This example had a kernel size of 3
- Ends require special care
- Trick is to pick the kernels correctly

$$o(t) = k_0*i(t-1)+k_1*i(t)+k_2*i(t+1)$$

| in | out |
|---|---|
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 4 |
| 5 | 5 |
| 6 | 6 |
| 7 | 7 |



$$o(6) = k_0*i(5)+k_1*i(6)+k_2*i(7)$$

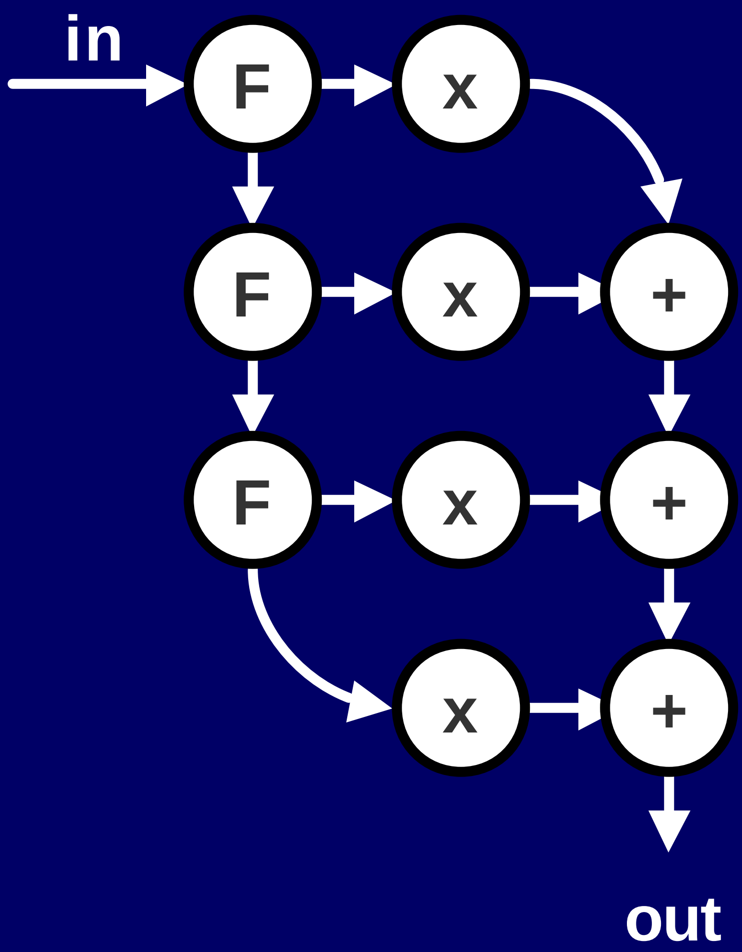
# A Simple “Low Pass” Filter

- Very common kernel is B-Spline (approximation to a Gaussian)
- k = [ 1/4, 1/2, 1/4 ]

- Soft low-pass filter
- Affects a range of frequencies
  - apply repeatedly to dull lower frequencies

# Cascades of filters

- A filter breaks a signal in two
- Chain them together to break a signal into pieces
- Alter each piece, and add them back together



# Motion Misconception 1

- Low pass filters do not necessarily remove noise!
  - They remove high frequencies!
- A heuristic for identifying noise
  - Real motions usually don't have much high frequencies, so if they're there...
- High frequencies give motions their "snap"

# Example 3: Adding / Blending

- Mix two (or more) signals together
- Interpolate between motions
  - Interpolate the character between its pose in the motions
- Get poses in between two originals
  - may or may not be meaningful
- Must do interpolation between poses
  - some kinds of signals (quaternions) don't really add

# Time Alignment

- Poses must correspond for blends to make any sense
  - Halfway between lying and standing?
  - Halfway between foot up and down in walk?
- Warp time to make things work out
  - Manually specify correspondences
  - Automatic dynamic time warping

# Uses of Blending

- Blends work if they are quick
  - What's halfway between a walk and a run?
  - Who cares if its really brief!
- Transitions
  - Make sure the poses meet up
- Looping
  - Transition between the beginning and end

# Does this work?

## Yes!

- Easy to do!
- Use for short overlaps
- Reprsentation Independent!

## No!

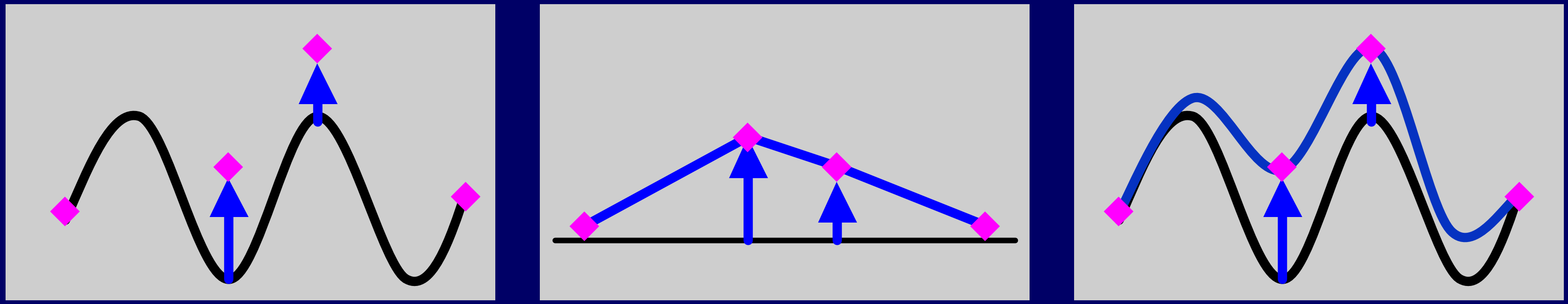
- No guarantees
- Unprincipled
- Need Time Alignment
- Need Corresponding Motions
- Must deal with angles

# How about adding something else?

- Create a "special motion" just for adding into a motion
- Pick a special motion with desired properties
  - if you want to preserve the pose at certain times, the motion has zero value
  - if you don't want to add certain frequencies, pick a motion without those frequencies

# Motion Displacement Maps (aka Motion Warps)

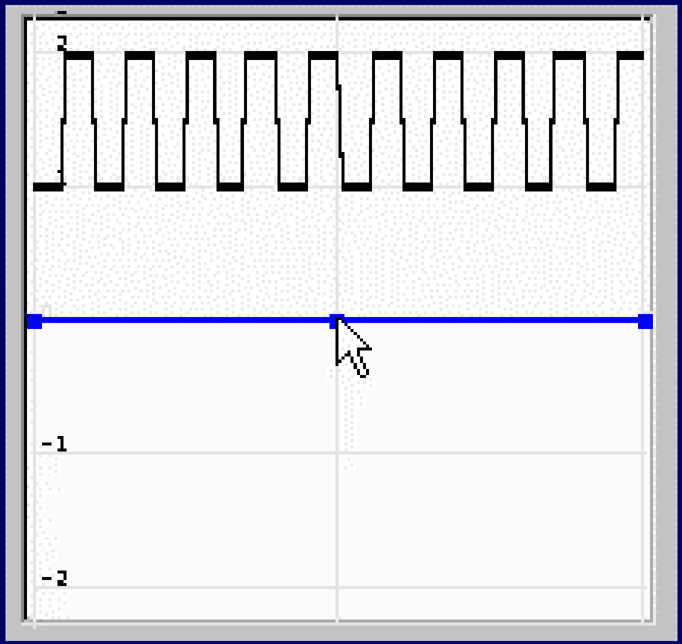
- Keyframe the displacement maps
  - zero where you don't want to change
  - interpolate the changes to make



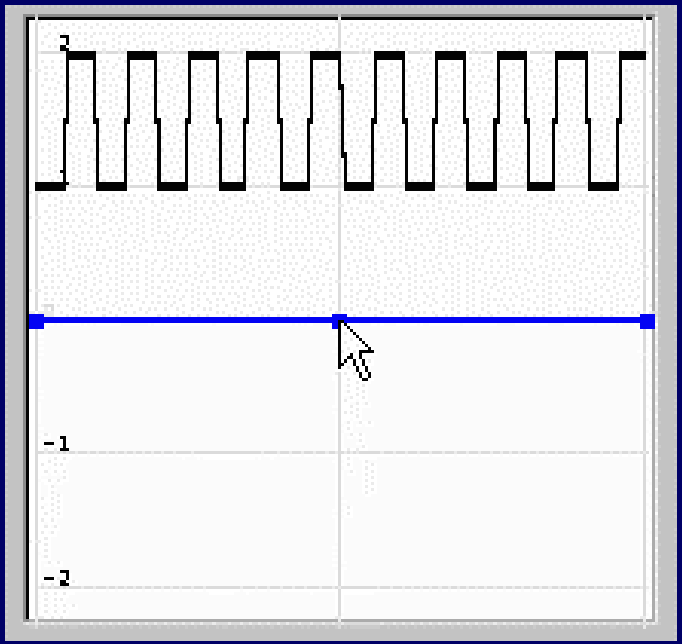
- Compute changes at key frames
  - subtract from original
- Intepolate to propagate changes

# Motion Warps

- Choose how to interpolate the changes



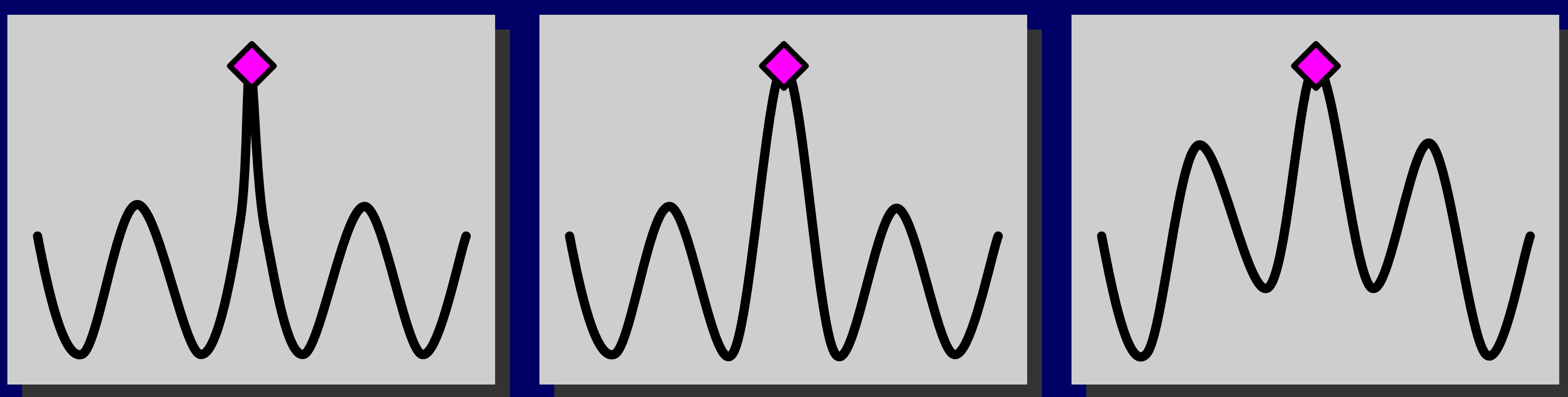

Interpolating Cubic




linear

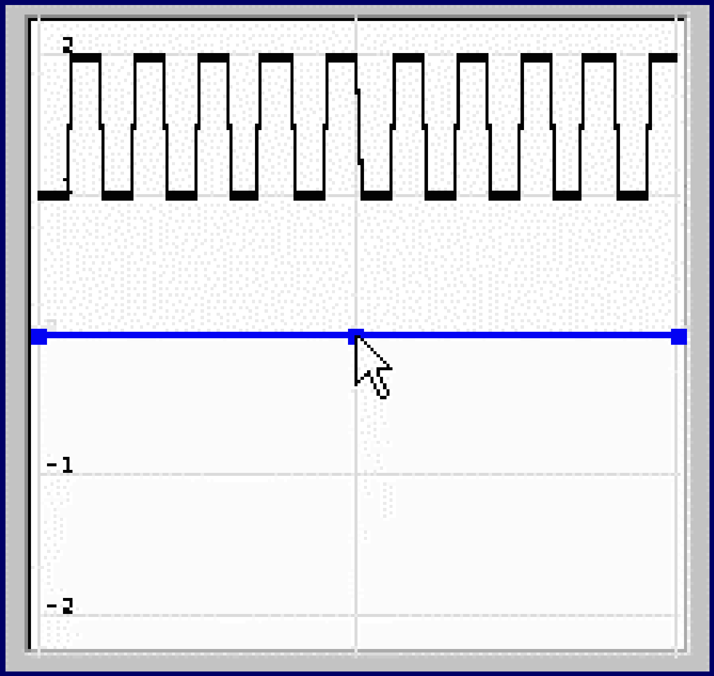
# Control of Scale

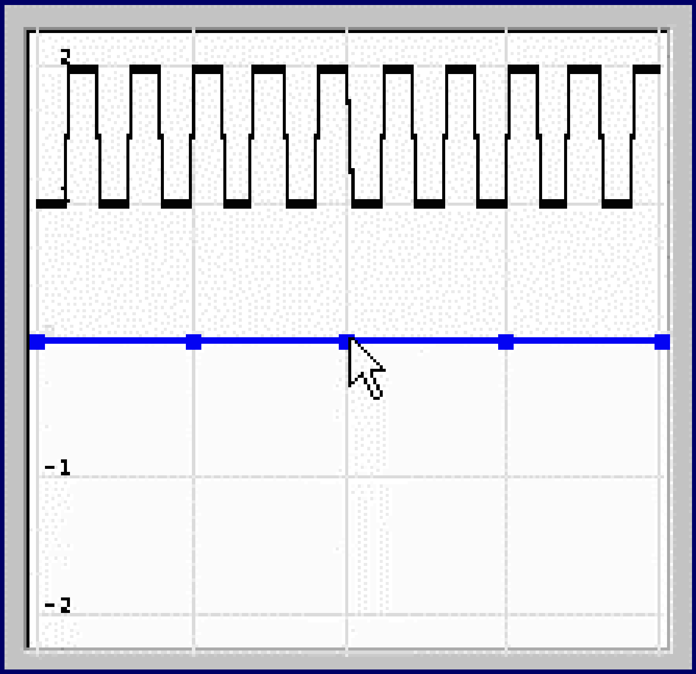
- Key spacing sets the size of changes
- Representation of original motion doesn't matter
- Can make any size change you want



# Control of Scale

- We specify as much (or little) as we want - not how much representation says!



# Motion Warping

## It Works!

- Easy to do
- Independent of initial motions form
- Use existing tools
- Propagate changes
- Control of range
- Preserve frequency content of original

## It has problems

- No control over non-key frames
- Addition may not be meaningful
- Can't preserve constraints
- Need interpolating displacement curve

# Other Motion Signal Processing Tricks

- Apply any signal processing operation to a motion
  - you may (or may not) get a useful result
- Motion concepts and signal concepts may not map
- There are lots of methods for signal processing to try
  - wave shaping, non-linear filtering, noise reduction, ...

# Some other resources

- Course Materials on-line (coming soon!)
  http://www.cs.wisc.edu/graphics/MotionEditing
- Motion Editing Mailing List
  - majordomo@cs.wisc.edu
  - subscribe moedit