Wii Remote
Strategies and Algorithms

Steve Rabin
Principal Software Engineer
Software Development Support Group

Nintendo

Wii SUMMIT 2008

Agenda

- Pointer functionality
- Accelerometers
  - – Understanding accelerometers
  - – Gesture recognition algorithms
    - Wii Sports case study
  - – Steering
- Wii Balance Board

3D Pointing: Targeting

- Aiming or Choosing
  - Onscreen feedback required

- Hand Shakiness is an Issue
  - Use KPAD smoothing
  - KPADSetPosParam(chan, play, sensitivity);
    - <play> should be between 0 and 0.05 (full range [0,1])
    - Find ideal settings with "kpadsample" in SDK
    - Only adjust after KPADSetPosPlayMode has been decided (Tight vs Loose)

3D Pointing: Distance/Twisting/Gestures

- Distance
  - Absolute distance can be computed
    - But only use relative distance
  - Could use distance to zoom
  - Smooth with KPADSetDistParam()
- Twisting
  - Smooth with KPADSetHoriParam()
  - Could also use accelerometer
- Gestures
  - Drawing symbols for spell casting
  - Use directional flicks to augment actions

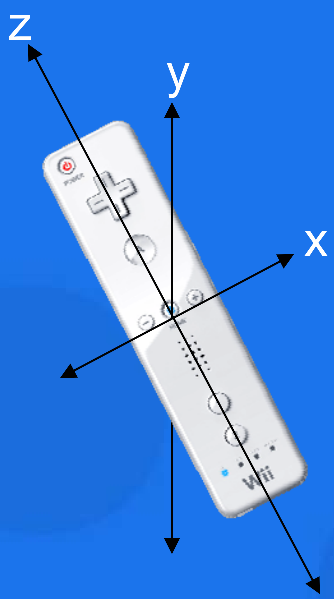
Nintendo

Accelerometers

+/-2.1G

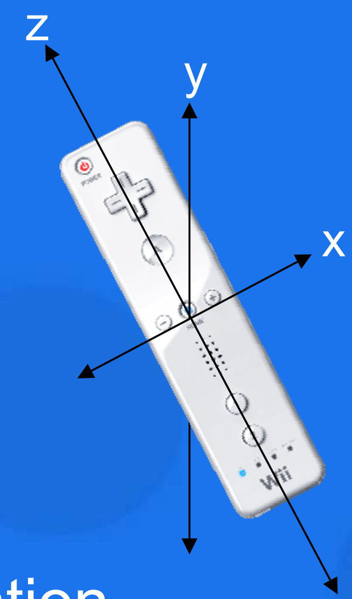
+/-3.4G

Understanding Accelerometers



1. Gravity is a force
   - (an acceleration)
2. Start and stop sweep movement
   - x-axis: Acceleration followed by deceleration
   - y-axis: Only affected by gravity
   - z-axis: Arm imparts a centripetal force on remote
3. Simulated drum hit
   - x-axis: Not affected much
   - y-axis: Gravity + acceleration/deceleration
   - z-axis: Centripetal force

Accelerometer Lessons



- Acceleration ≠ velocity ≠ position
- Accelerometers always detect gravity
- Movement creates acceleration and deceleration
- Accelerometers detect *change* in velocity
  - Constant speed = no acceleration!
- Some rotations can't be detected by accelerometers
- Accelerometers are amazingly accurate & precise
  - Hand shakiness needs to be dealt with

Accelerometer Applications

Gesturing

Steering

Accelerometers: Advice for Designing Gestures

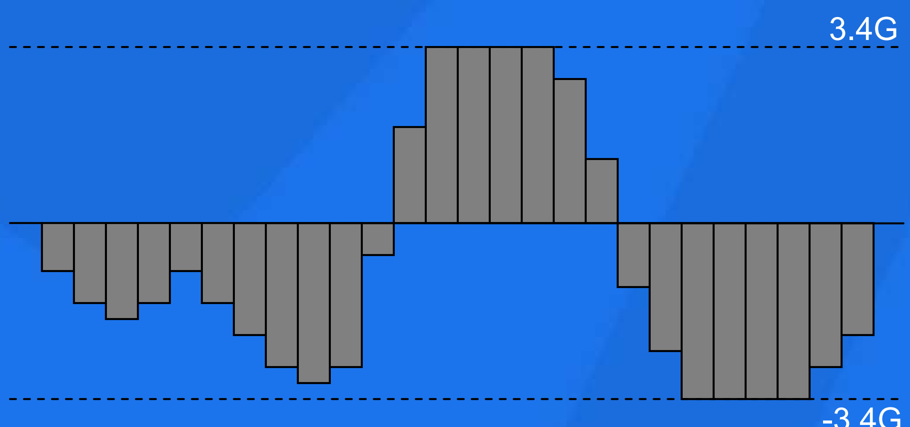
- Don't wear out the player
  - Keep frequency/duration of vigorous gestures low
- Common issues
  - Missed recognition
    - Not sensitive enough
    - Player not holding controller correctly
  - Incorrect recognition
    - Gestures are too similar to each other
    - Use more context sensitive gestures
  - False positives
    - Expected gesture is too subtle or too similar to gravity
    - Use context sensitive gestures

Accelerometers: Difficult to Track 3D Position

- Accelerometers measure acceleration
  - Not velocity or position
  - But, double integral of acceleration is position!
- Difficult to decouple gravity from movement
  - People hold controller differently
  - Orientation changes over duration of movement
  - Complicated algorithms can make educated guesses at the influence of gravity
  - Error makes this extremely difficult
- No known method to reliably track position only with accelerometers

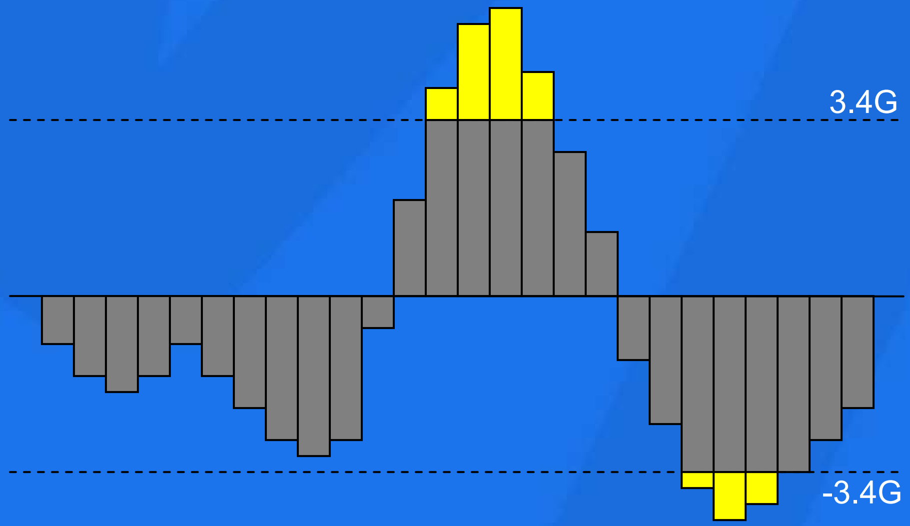
Preprocess Signal to Estimate True Magnitude

- Wii Remote detects +/-3.4G
  - Easy to max out acceleration



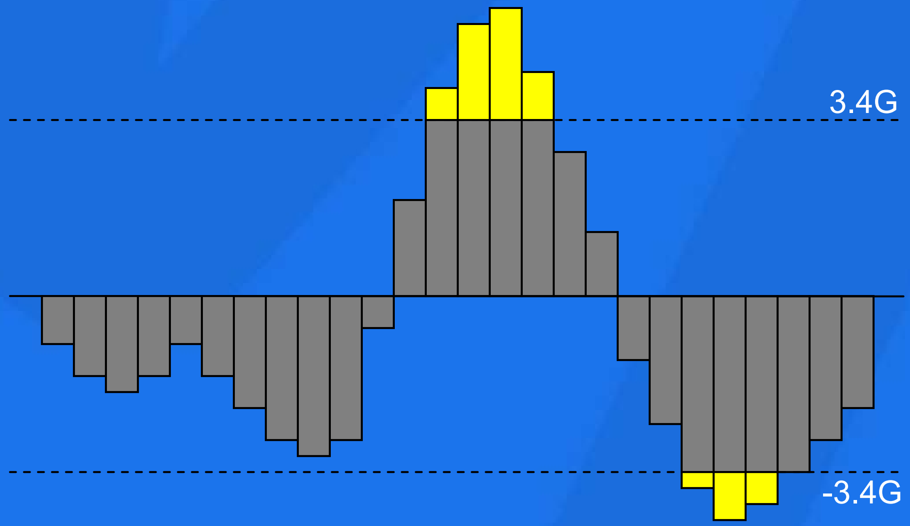
Preprocess Signal to Estimate True Magnitude

- Wii Remote detects +/-3.4G
  - Easy to max out acceleration



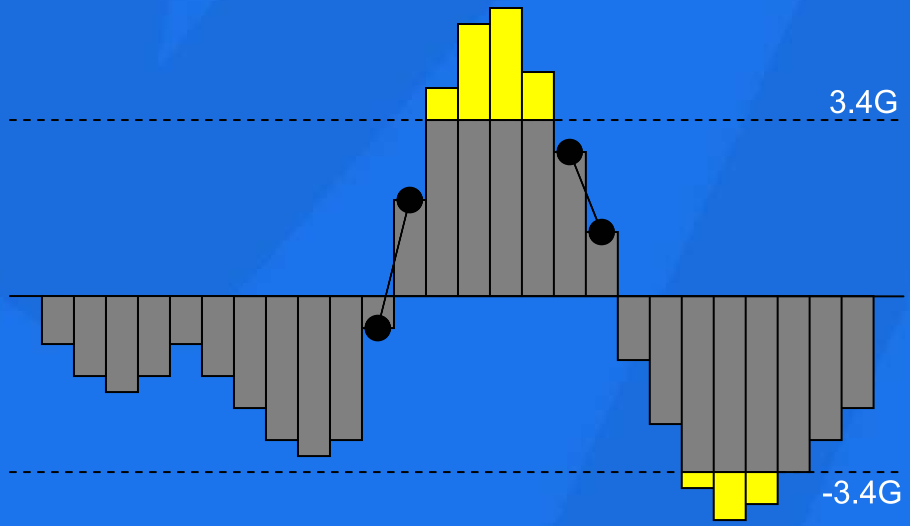
Estimate True Magnitude: Spline Method

- Use spline to estimate actual magnitude
  - Hermite spline (C1 continuity)
  - Bezier spline (C2 continuity)



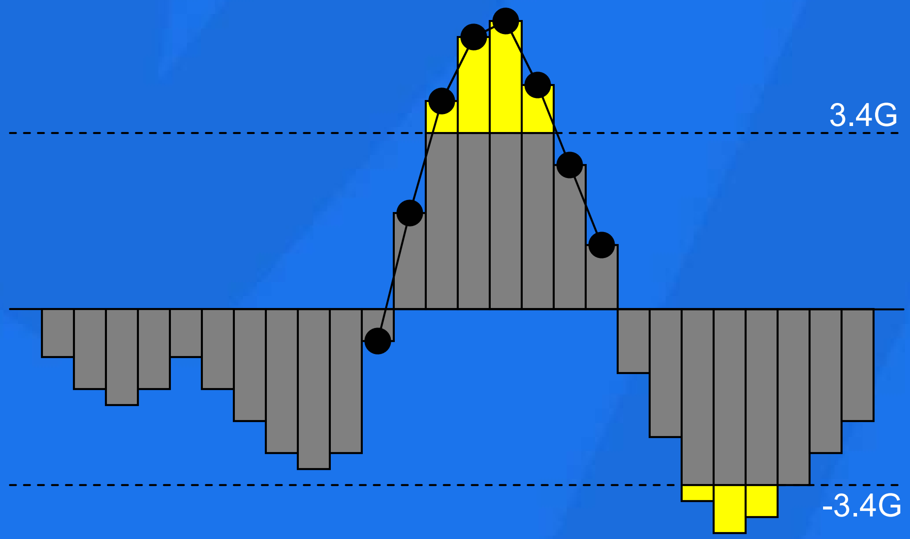
Estimate True Magnitude: Spline Method

- Use spline to estimate actual magnitude
  - Hermite spline (C1 continuity)
  - Bezier spline (C2 continuity)



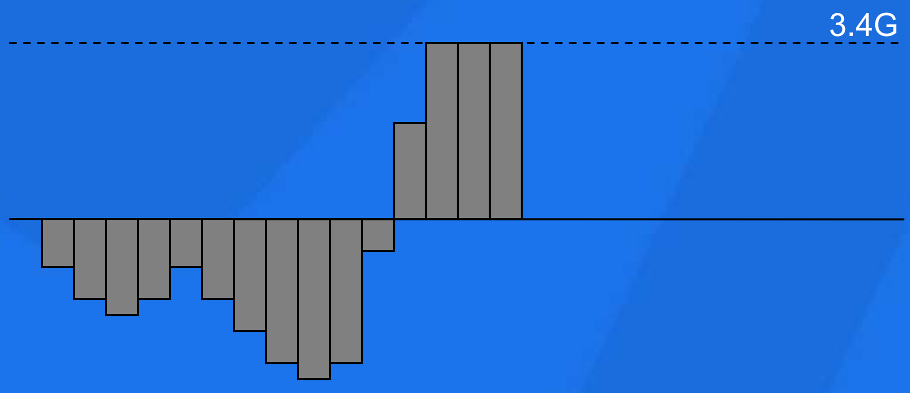
Estimate True Magnitude: Spline Method

- Use a spline to estimate actual magnitude
  - Hermite spline (C1 continuity)
  - Bezier spline (C2 continuity)



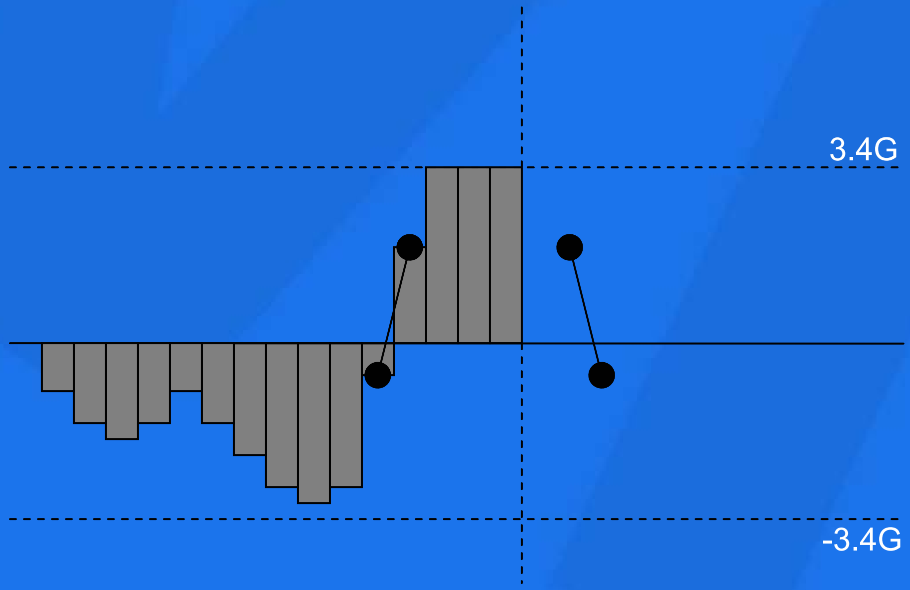
Estimate True Magnitude: Spline Method

- Might need to estimate as data comes in
  - Option #1: Predict end control point



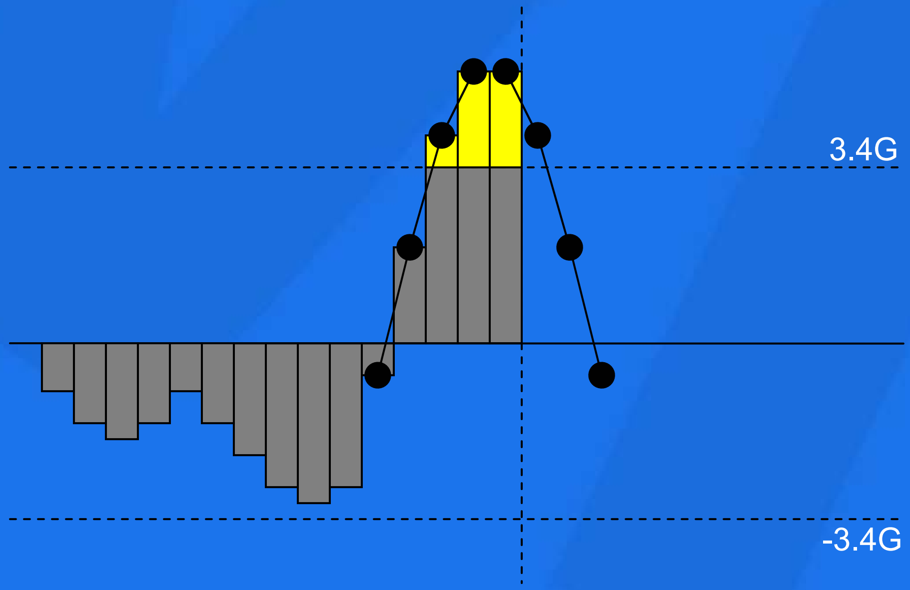
Estimate True Magnitude: Spline Method

- Might need to estimate as data comes in
  - Option #1: Predict end control point



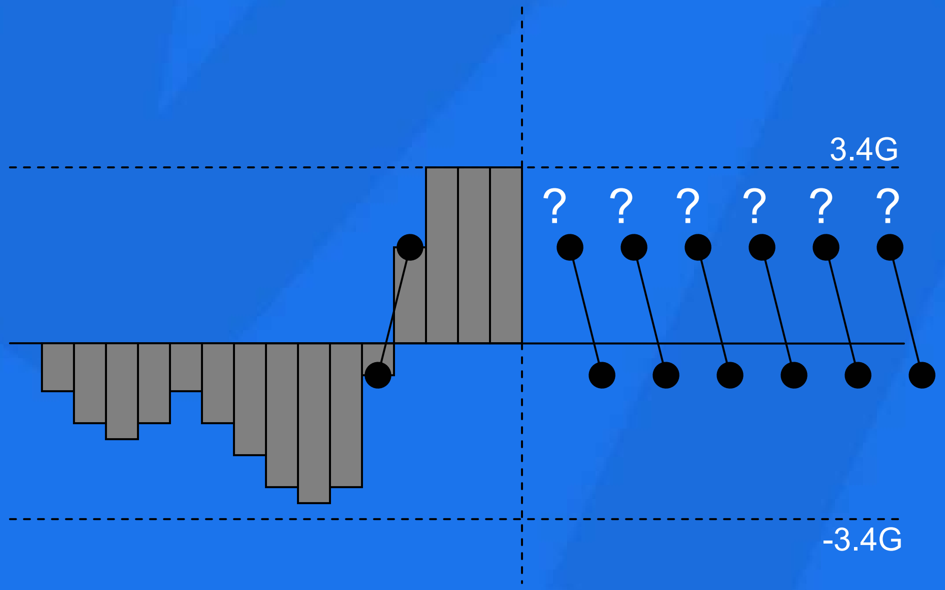
Estimate True Magnitude: Spline Method

- Might need to estimate as data comes in
  - Option #1: Predict end control point



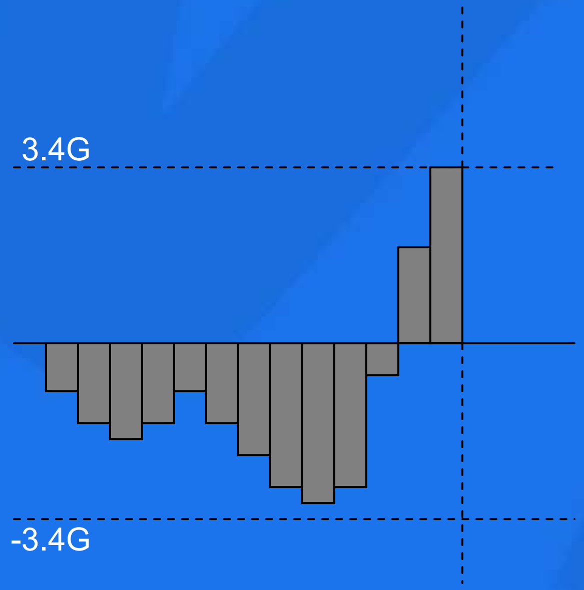
Estimate True Magnitude: Spline Method

- Might need to estimate as data comes in
  - Option #1: Predict end control point
    - Must guess at width... But how wide?



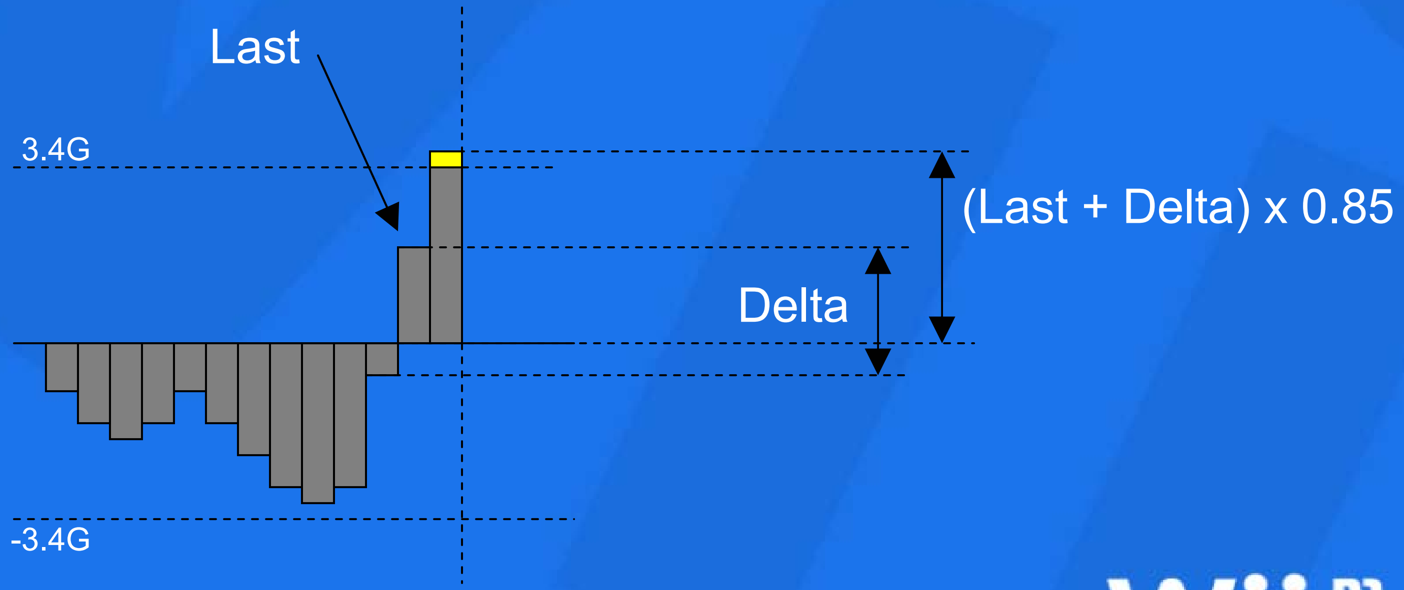
Estimate True Magnitude: Dampen Method

- Might need to estimate as data comes in
  - Option #2: Take delta, add to last, dampen



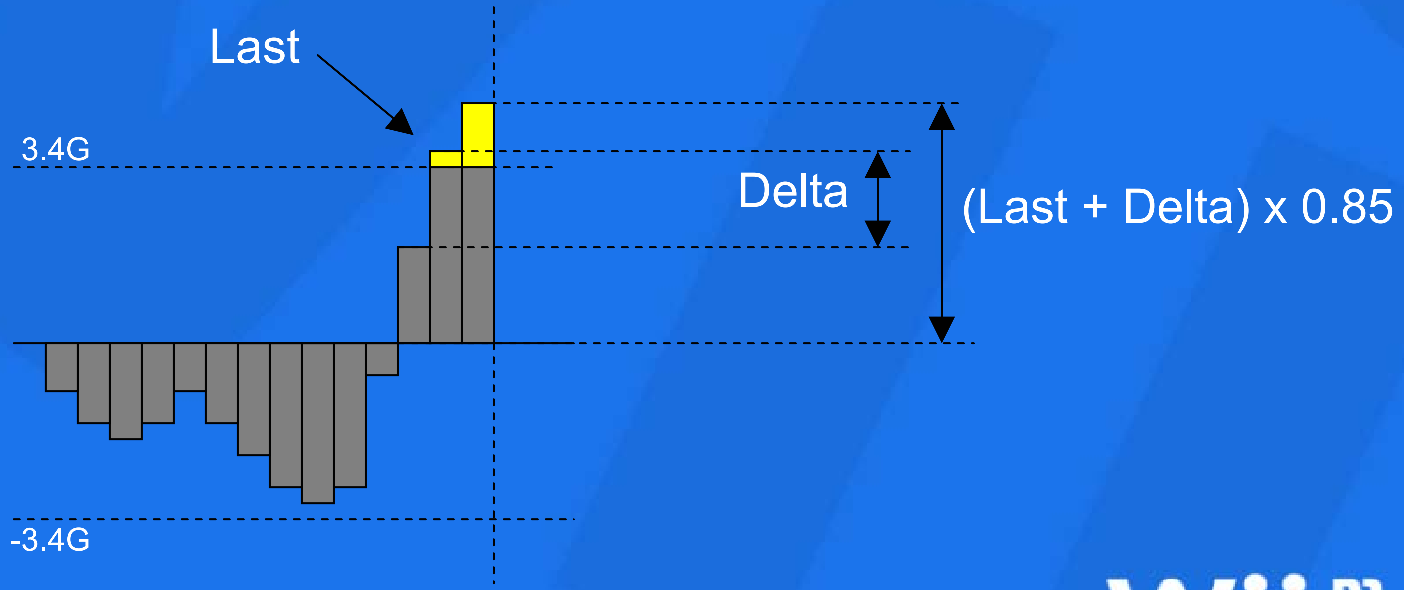
Estimate True Magnitude: Dampen Method

- Might need to estimate as data comes in
  - Option #2: Take delta, add to last, dampen



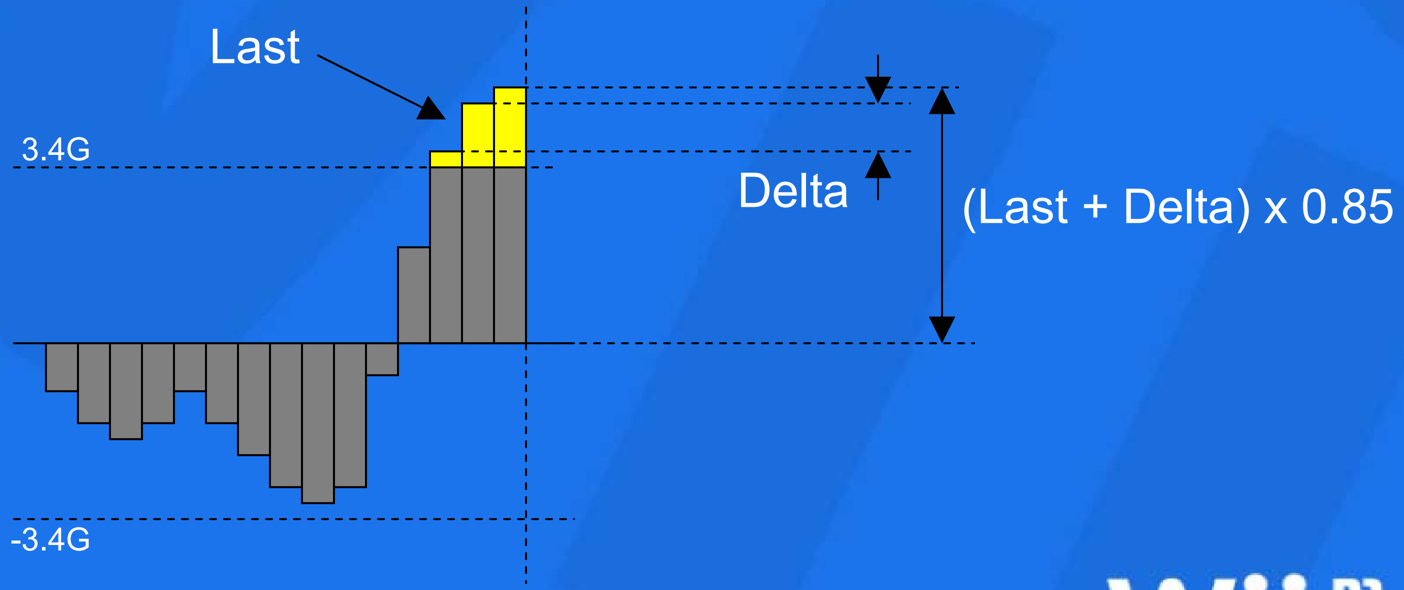
Estimate True Magnitude: Dampen Method

- Might need to estimate as data comes in
  - Option #2: Take delta, add, dampen



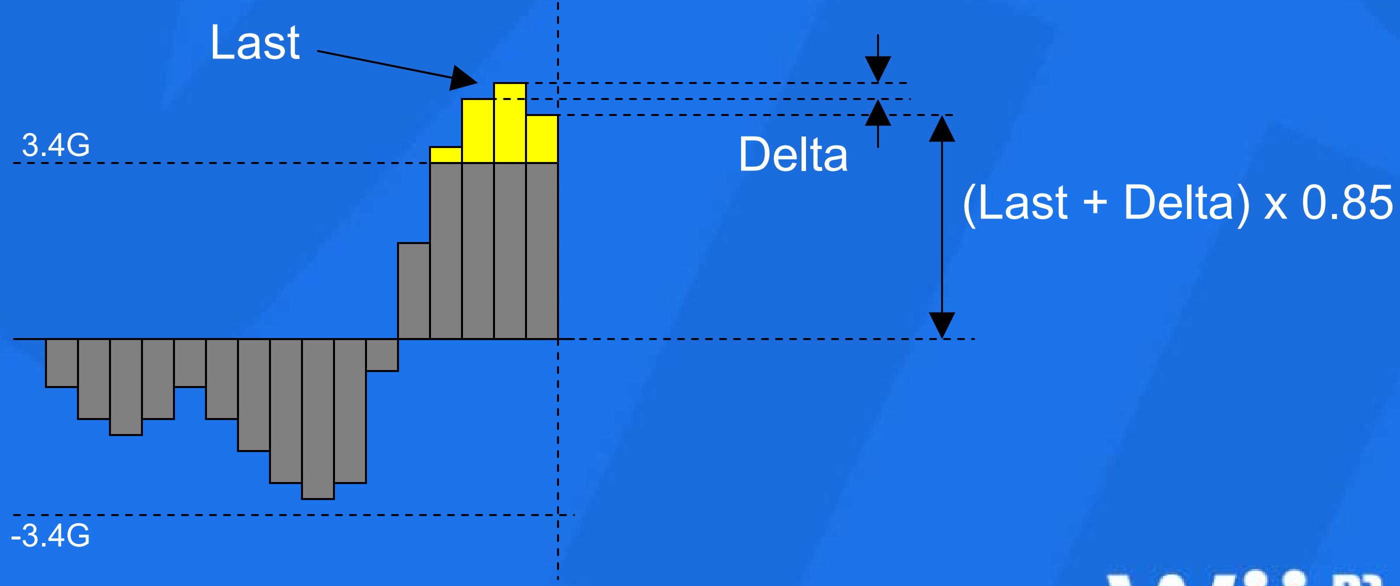
Estimate True Magnitude: Dampen Method

- Might need to estimate as data comes in
  - Option #2: Take delta, add, dampen



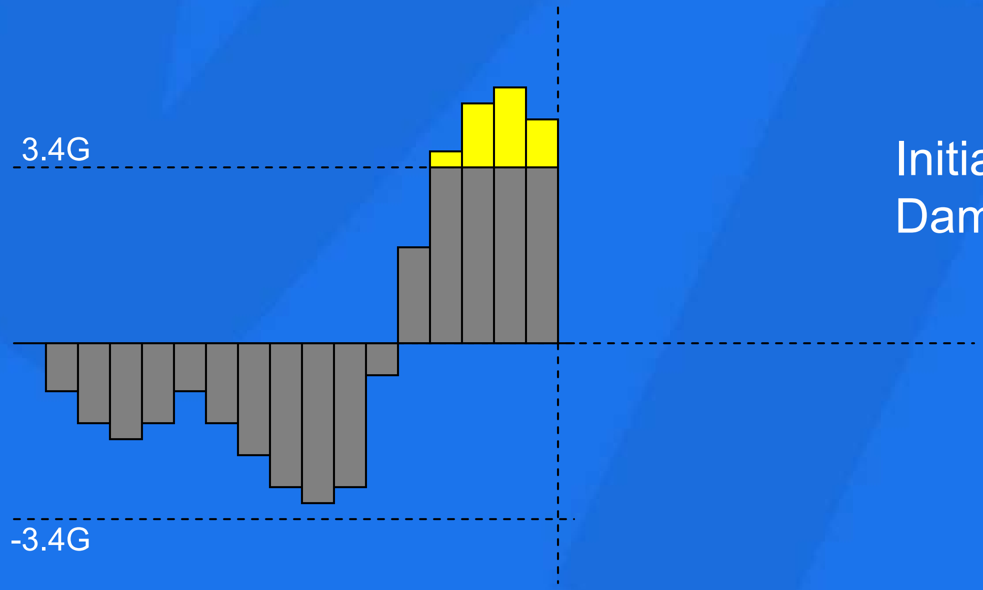
Estimate True Magnitude: Dampen Method

- Might need to estimate as data comes in
  - Option #2: Take delta, add, dampen



Estimate True Magnitude: Dampen Method

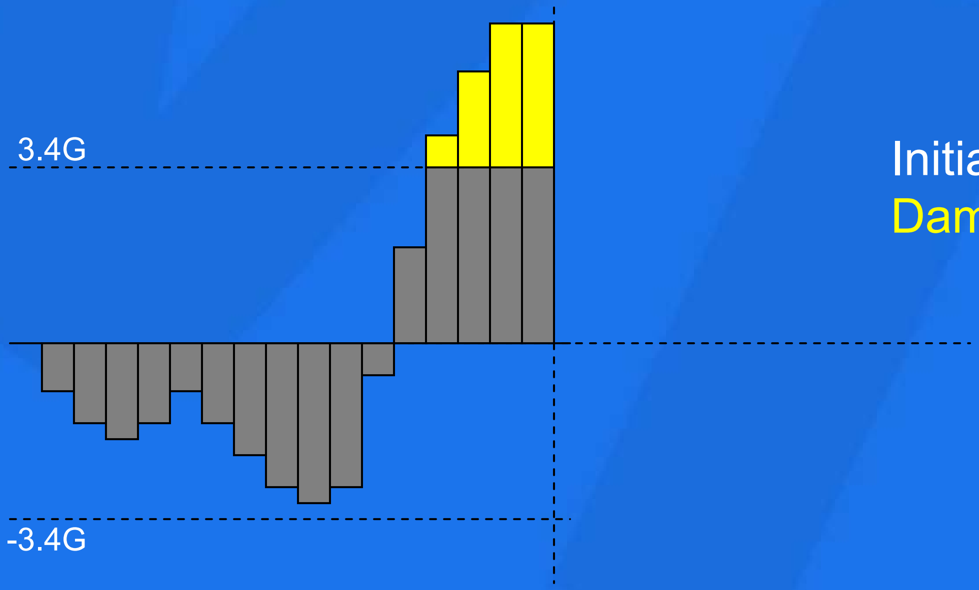
- Might need to estimate as data comes in
  - Option #2: Choosing dampening value is difficult



Initial Delta = 2.5G
Dampening = 0.85

Estimate True Magnitude: Dampen Method

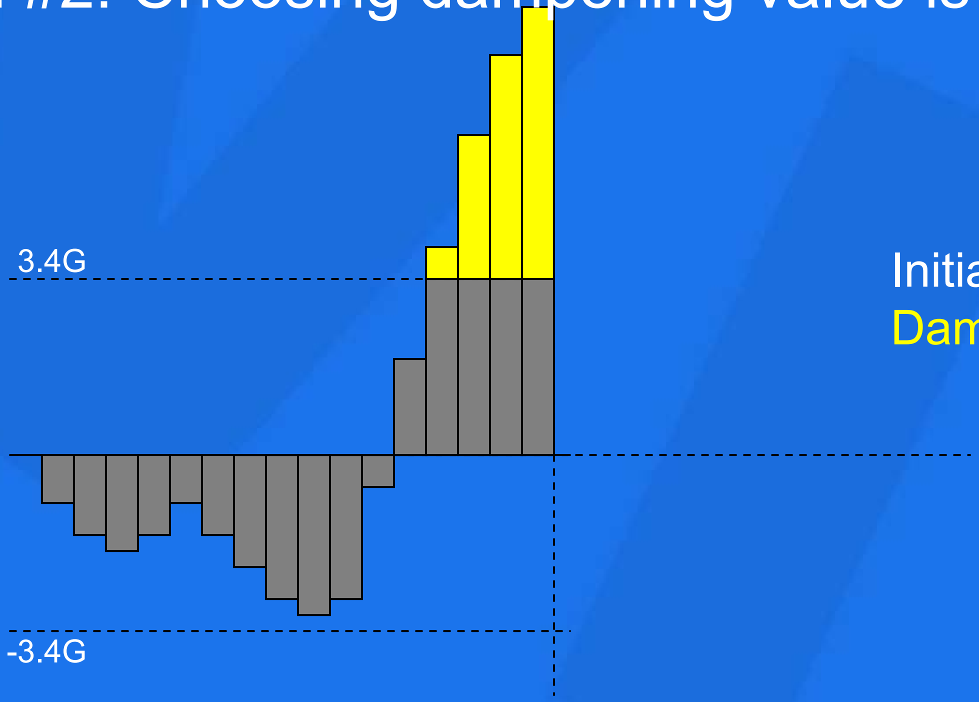
- Might need to estimate as data comes in
  - Option #2: Choosing dampening value is difficult



Initial Delta = 2.5G
Dampening = 0.90

Estimate True Magnitude: Dampen Method

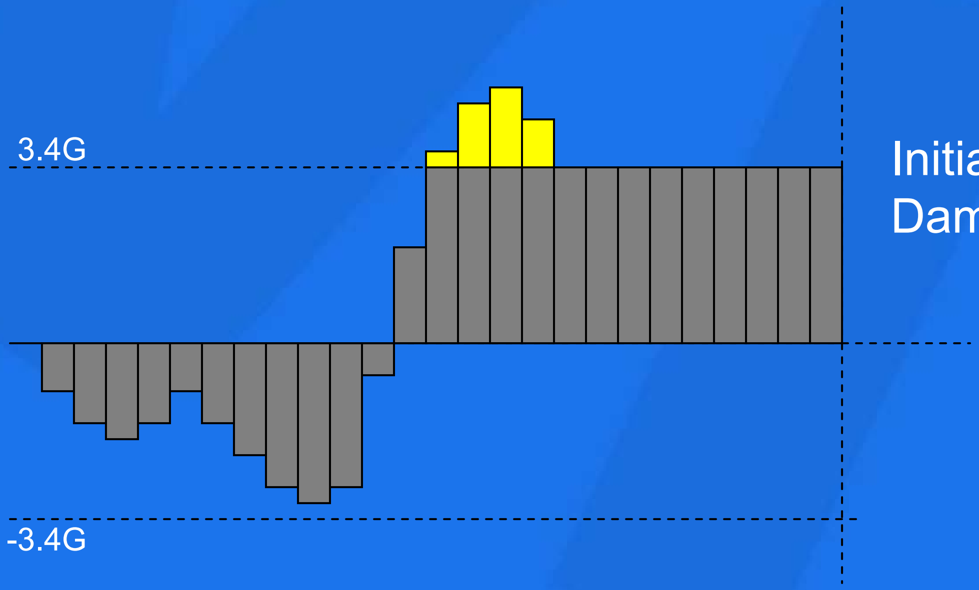
- Might need to estimate as data comes in
  - Option #2: Choosing dampening value is difficult



Initial Delta = 2.5G
Dampening = 0.95

Estimate True Magnitude: Dampen Method

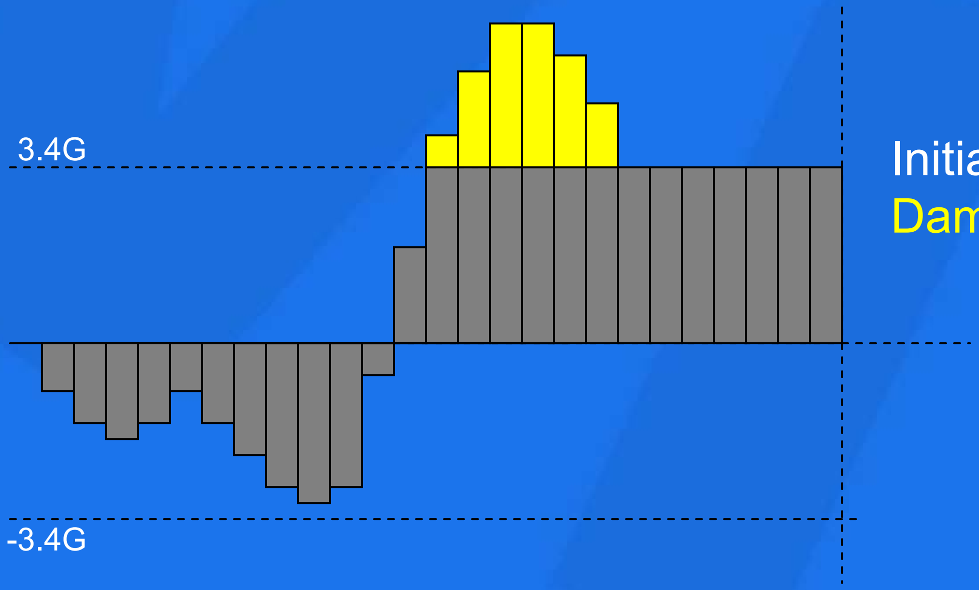
- Might need to estimate as data comes in
  - Option #2: Choosing dampening value is difficult (Initial delta and dampening determine period width)



Initial Delta = 2.5G
Dampening = 0.85

Estimate True Magnitude: Dampen Method

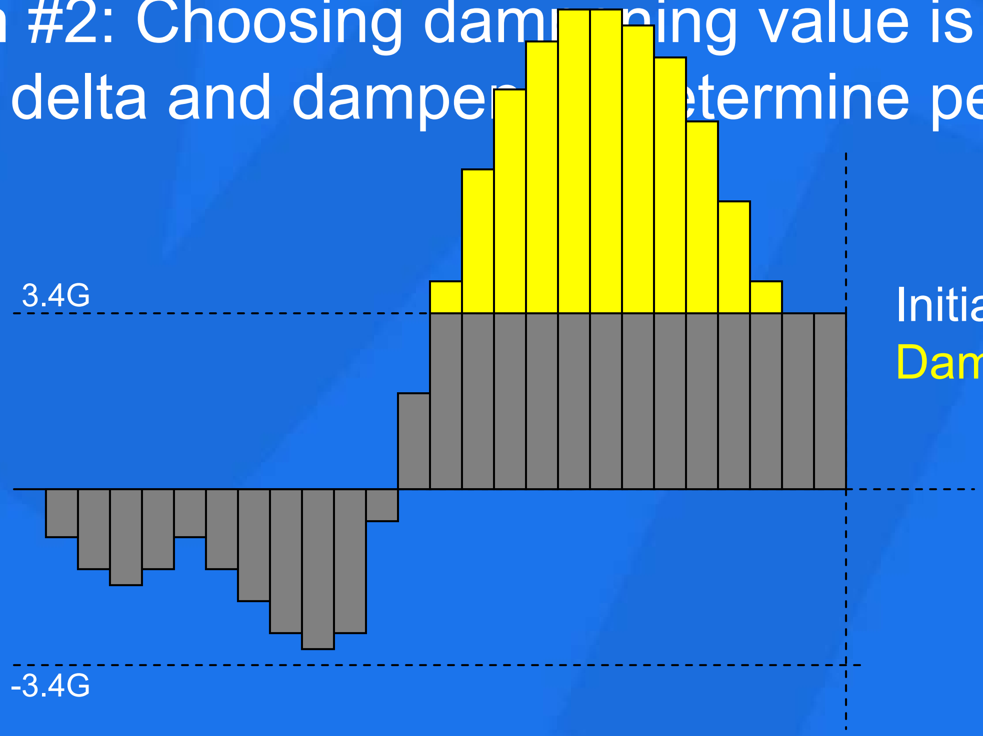
- Might need to estimate as data comes in
  - Option #2: Choosing dampening value is difficult (Initial delta and dampening determine period width)



Initial Delta = 2.5G
Dampening = 0.90

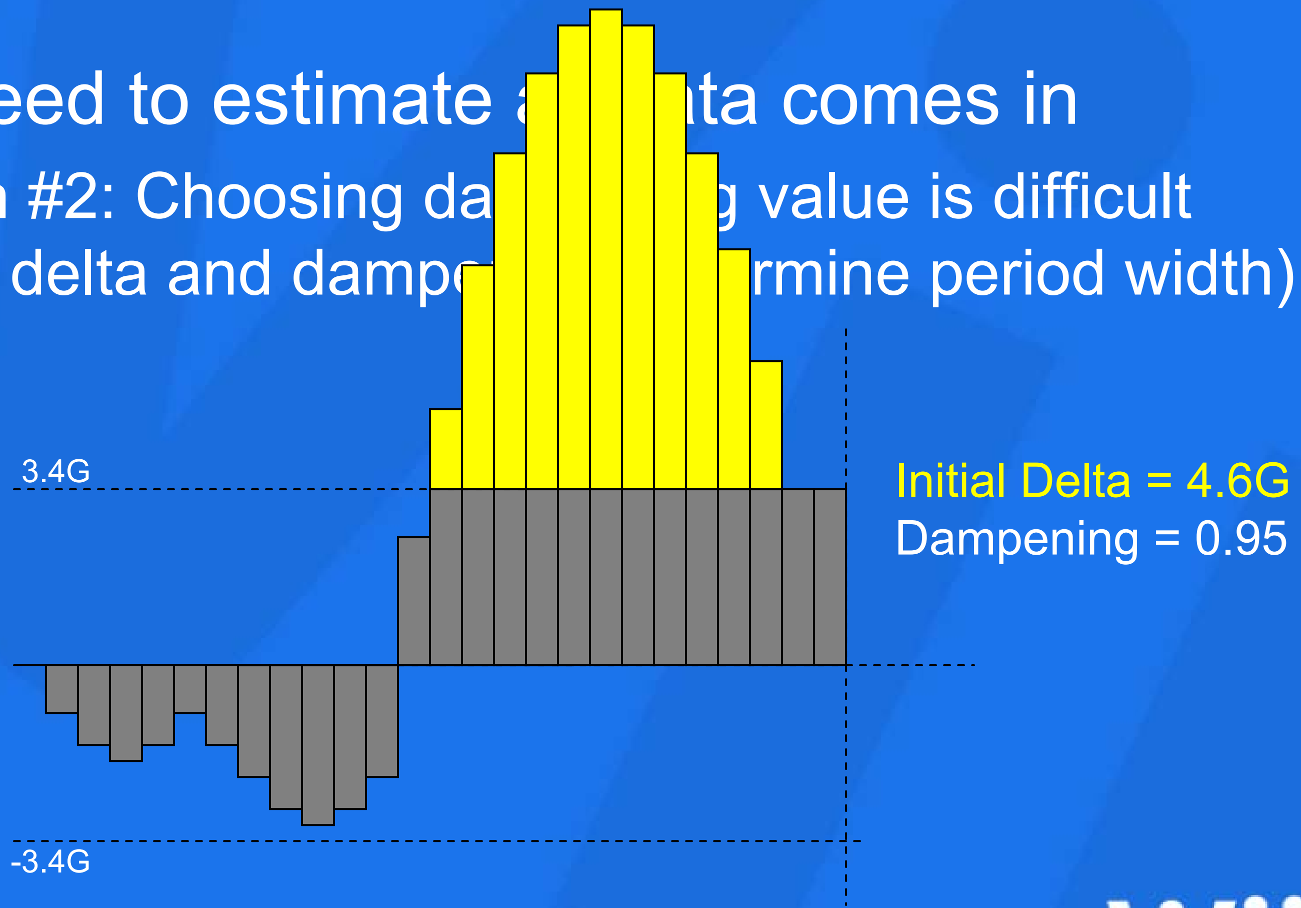
Estimate True Magnitude: Dampen Method

- Might need to estimate as data comes in
  - Option #2: Choosing dampening value is difficult (Initial delta and dampening determine period width)



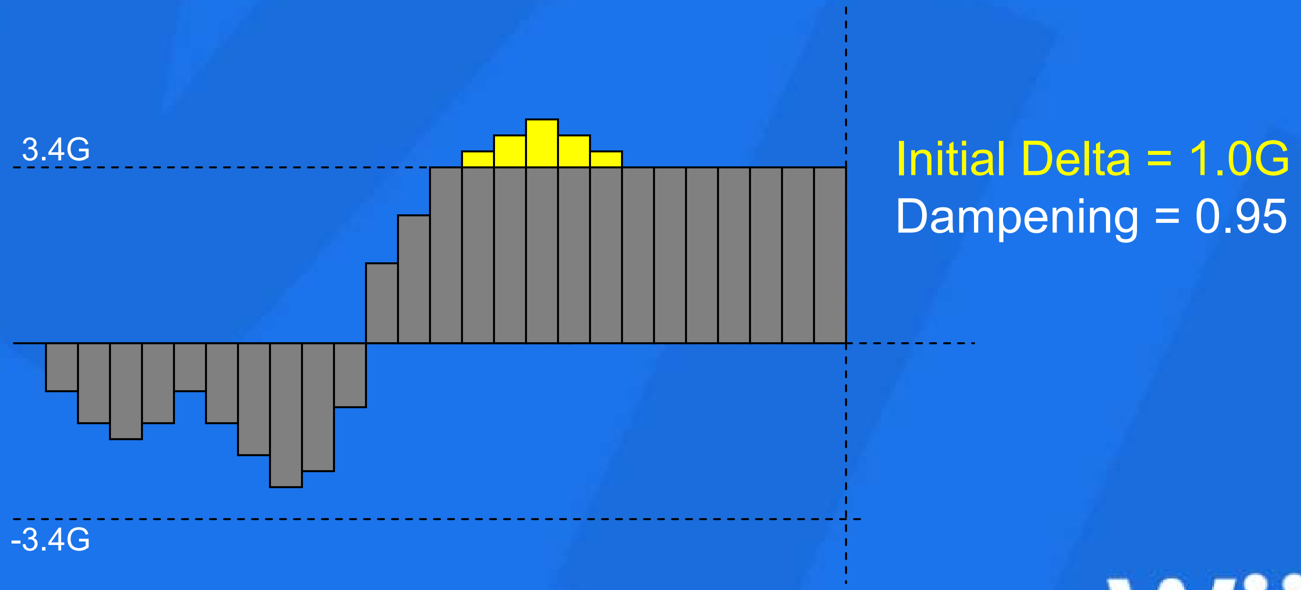
Estimate True Magnitude: Dampen Method

- Might need to estimate a ta comes in
  – Option #2: Choosing da g value is difficult (Initial delta and dampe rmine period width)



Estimate True Magnitude: Dampen Method

- Might need to estimate as data comes in
  - Option #2: Choosing dampening value is difficult (Initial delta and dampening determine period width)



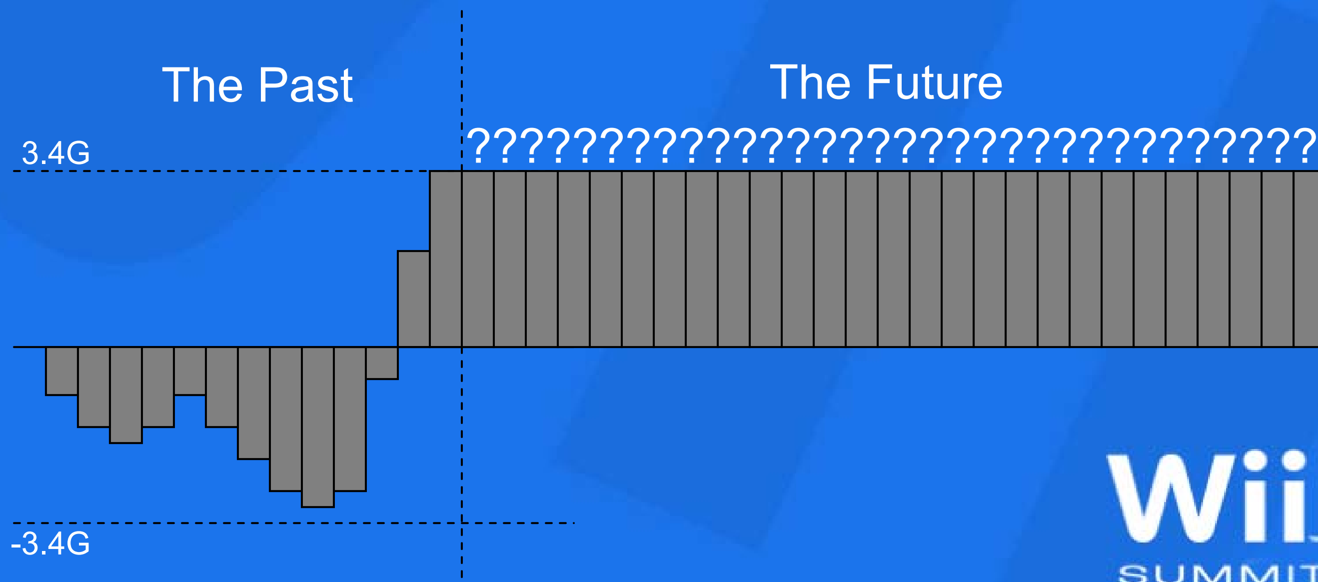
Width of Clamped Area

Initial Delta

Dampening	0.3G	0.5G	1.0G	1.5G	2.0G	2.5G
0.995	25	31	37	39	40	41
0.99	13	18	24	26	27	28
0.98	6	10	15	17	18	19
0.95	2	3	7	9	10	10
0.90	0	0	3	4	5	6
0.85	0	0	1	3	4	4

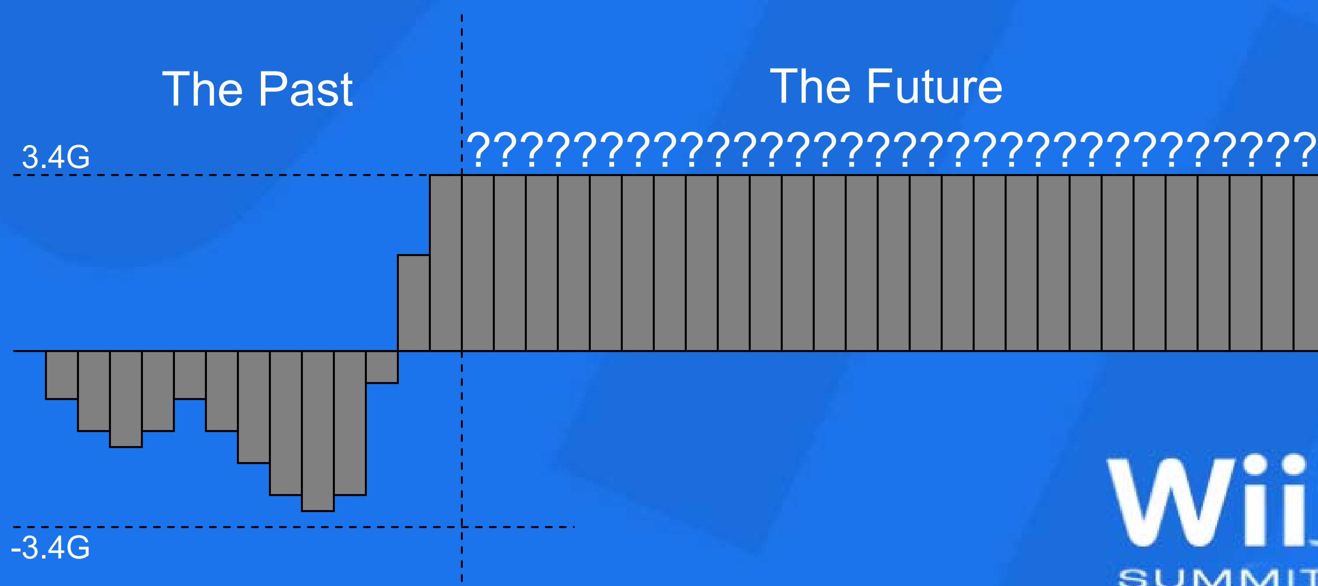
Estimate True Magnitude: Predict Clamped Width

- Ultimately must predict clamped width in order to predict missing magnitude
  - For spline method or dampen method
  - Player/situation dependant



Estimate True Magnitude: Player Modeling

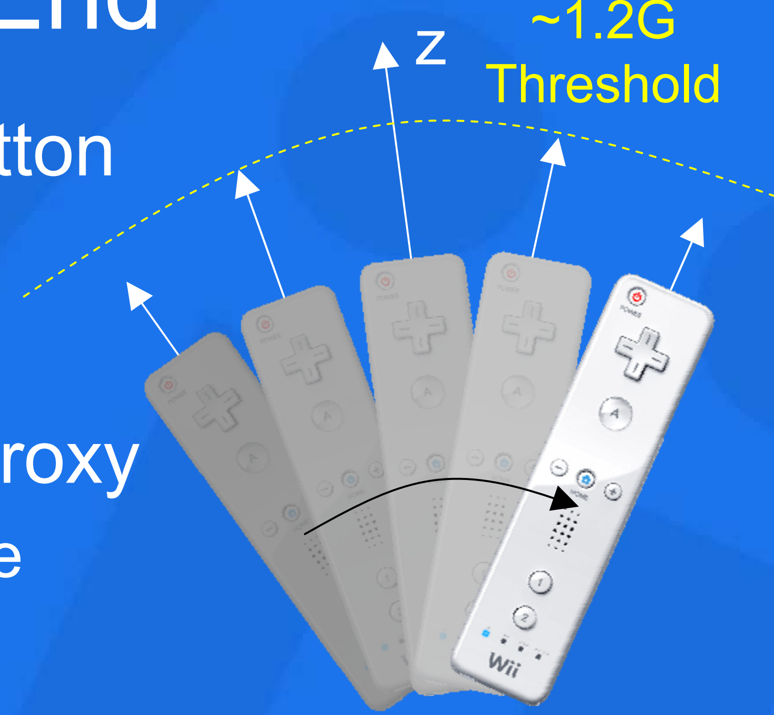
- AI statistical learning technique
- Track clamped length moving average on each axis
- Six moving averages to track
  - x-axis +, x-axis -, y-axis +, y-axis -, z-axis +, z-axis -



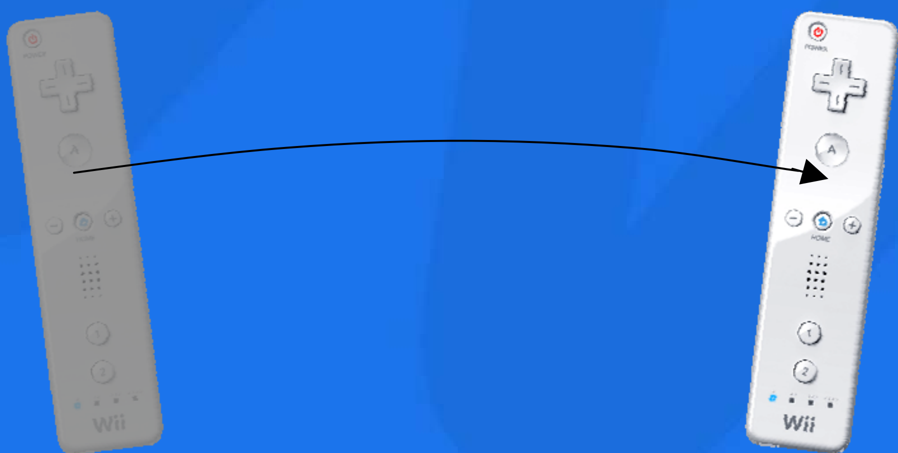
Detecting when Gestures Begin and End

- Player presses/releases button
  - Example: Drawing in the air

- Use centripetal force as a proxy
  - Moves cause centripetal force
    - Arm pivots at shoulder
    - Hand pivots at wrist
  - About 1.2G is a good threshold
    - Ignores non-gestures



Accelerometer Gesture Recognition: Simple vs Complex

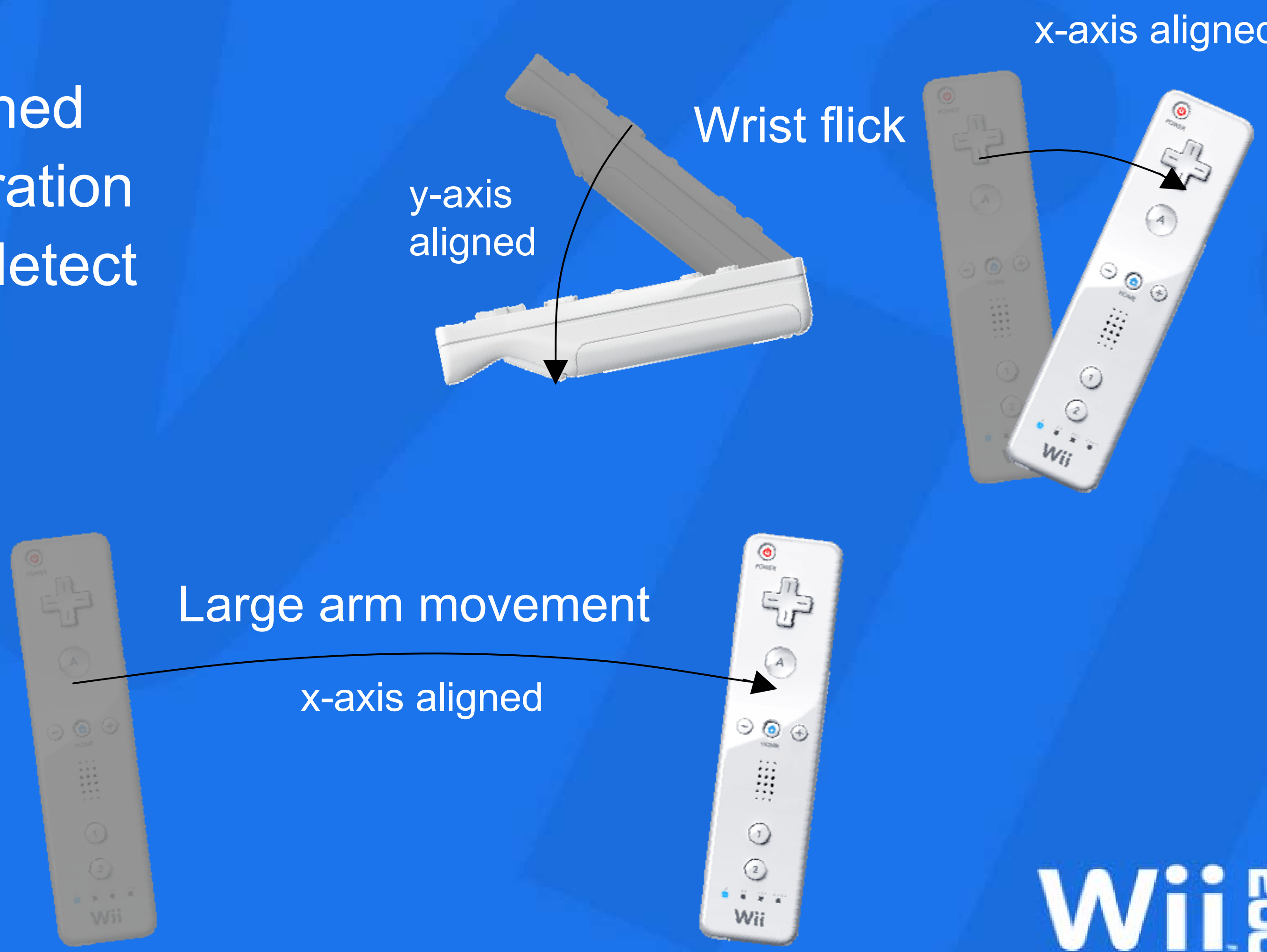


Simple

Complex

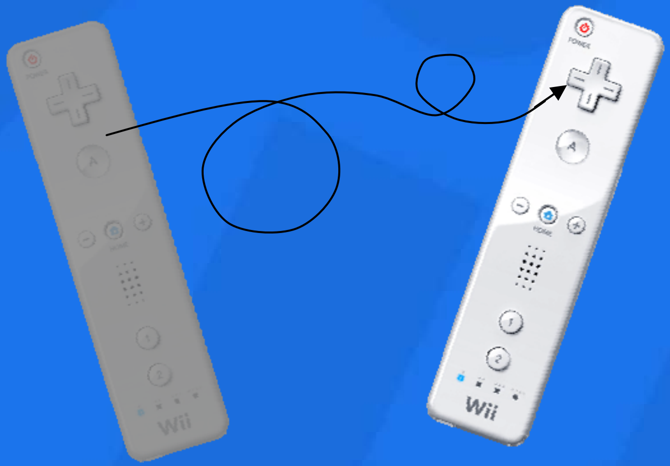
Accelerometer Gesture Recognition: Simple Motion

- Axis-aligned
- Short duration
- Easy to detect



Accelerometer Gesture Recognition: Complex Motion

- Multi-axis
- Longer duration
- Difficult to detect 100%
- Difficult to detect early



Multi-axis

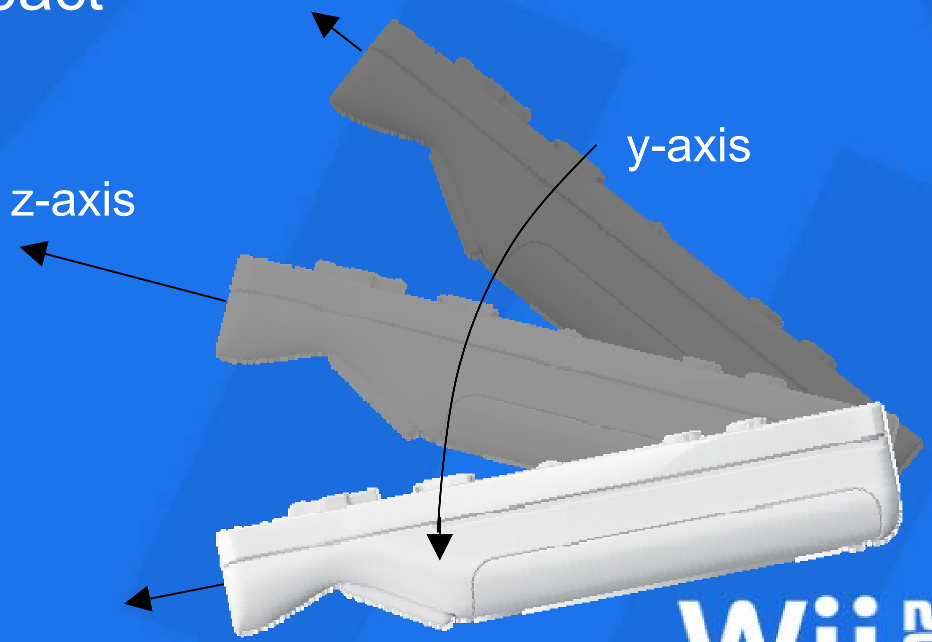
Gesture Recognition:
Simple Motion—Hits, Swipes, and Stabs

- These movements are axis-aligned
  - Easy to detect (using thresholds)
  - Natural player movement, simple to do

A Tale of Two Drums

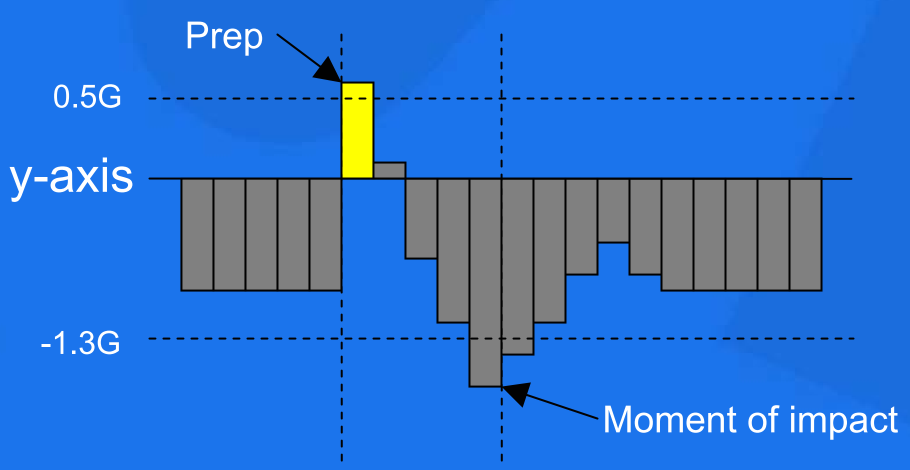
Drum Hit—Case Study #1

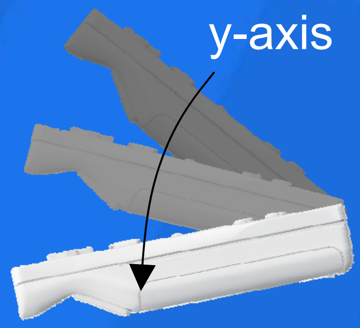
- Two aspects
  - Detect moment of impact
  - Detect strength of impact



Drum Hit—Case Study #1

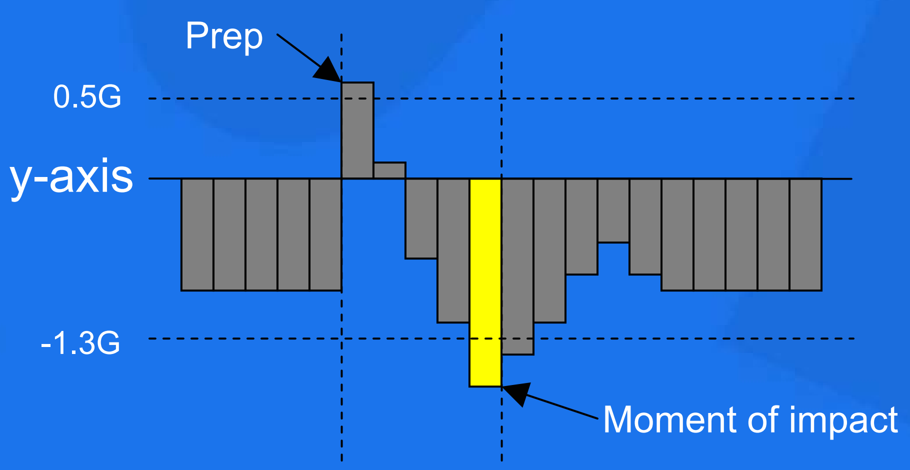
- Detect moment of impact
  - 0.5G "Prep" threshold will figuratively "cock trigger"

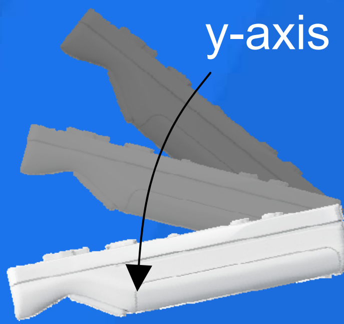




Drum Hit—Case Study #1

- Detect moment of impact
  - 0.5G "Prep" threshold will figuratively "cock trigger"
  - Once ready, -1.3G threshold represents moment of impact



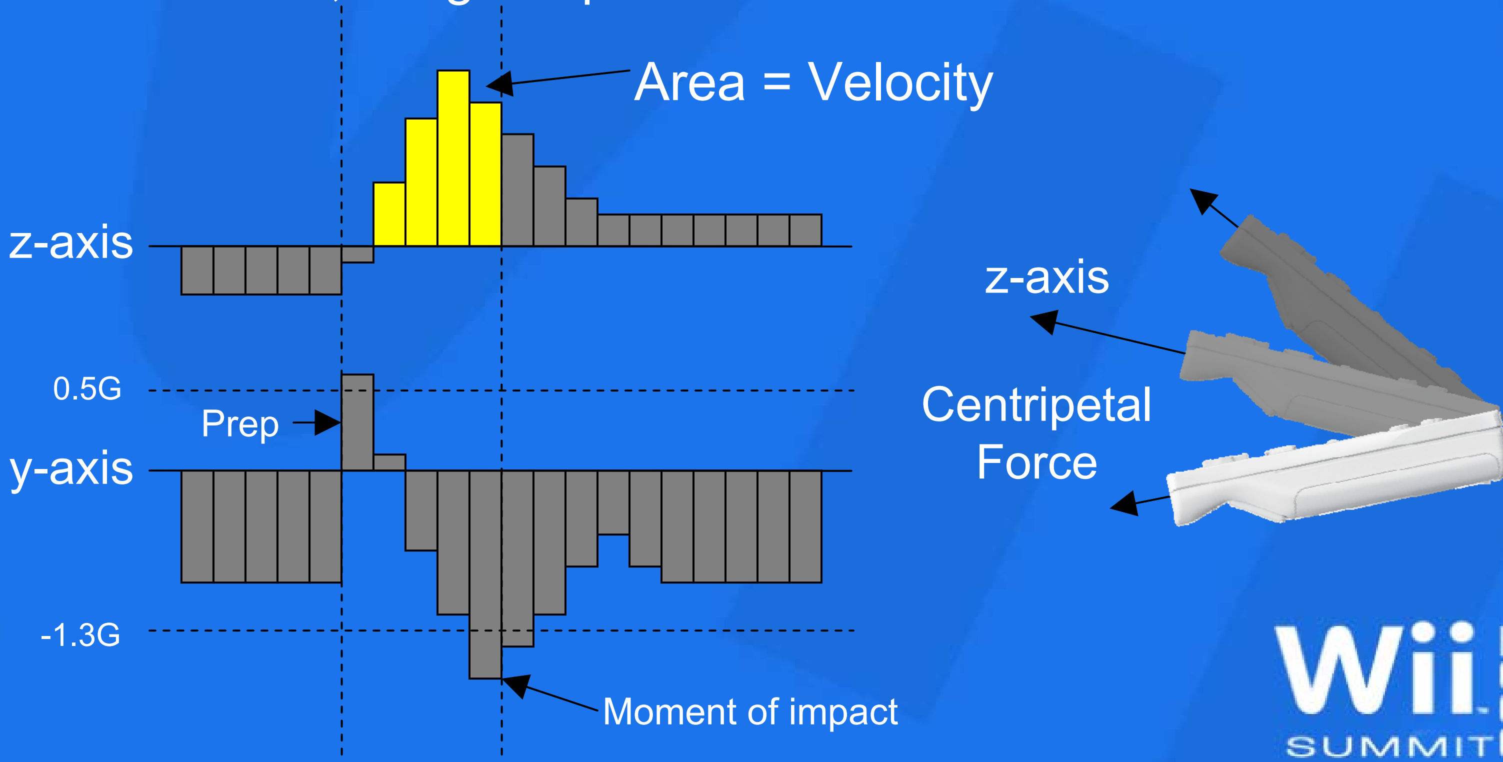


Nintendo

Wii SUMMIT 2008

Drum Hit—Case Study #1

- Detect strength of impact
  - Construct window between "prep" time and "impact" time
  - Within window, integrate positive acceleration on z-axis



Drum Solo!

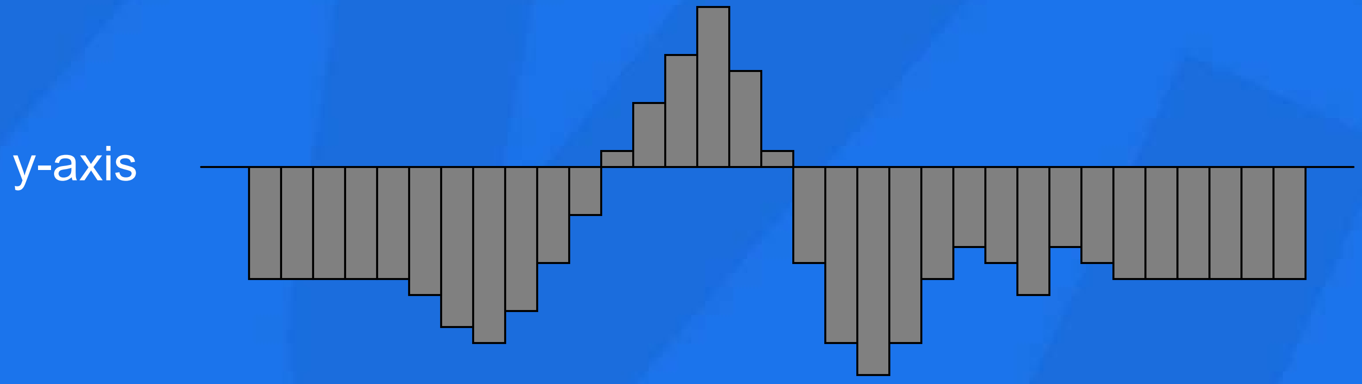
"It was sounding great, but, I could of used a little more cowbell"

Drum Hit—Case Study #2

- What if we want positional data?
  - Show drum stick going up/down in-sync with Wii Remote
  - Use actual on-screen motion/velocity to determine hit strength (loudness)

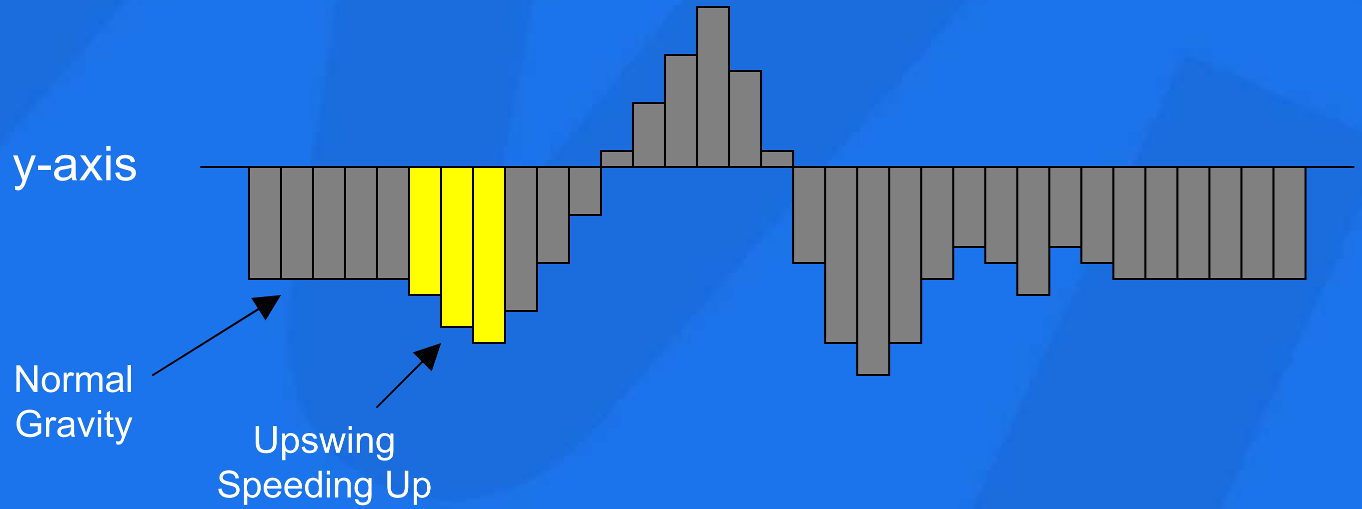
Drum Hit—Case Study #2

- Study up/down acceleration



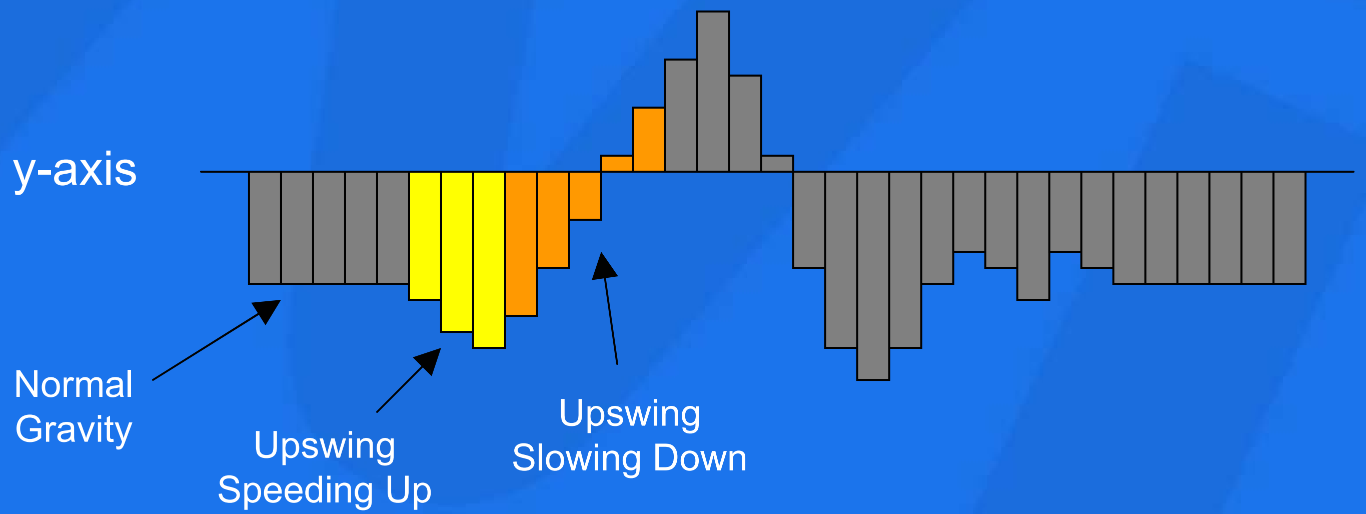
Drum Hit—Case Study #2

- Study up/down acceleration



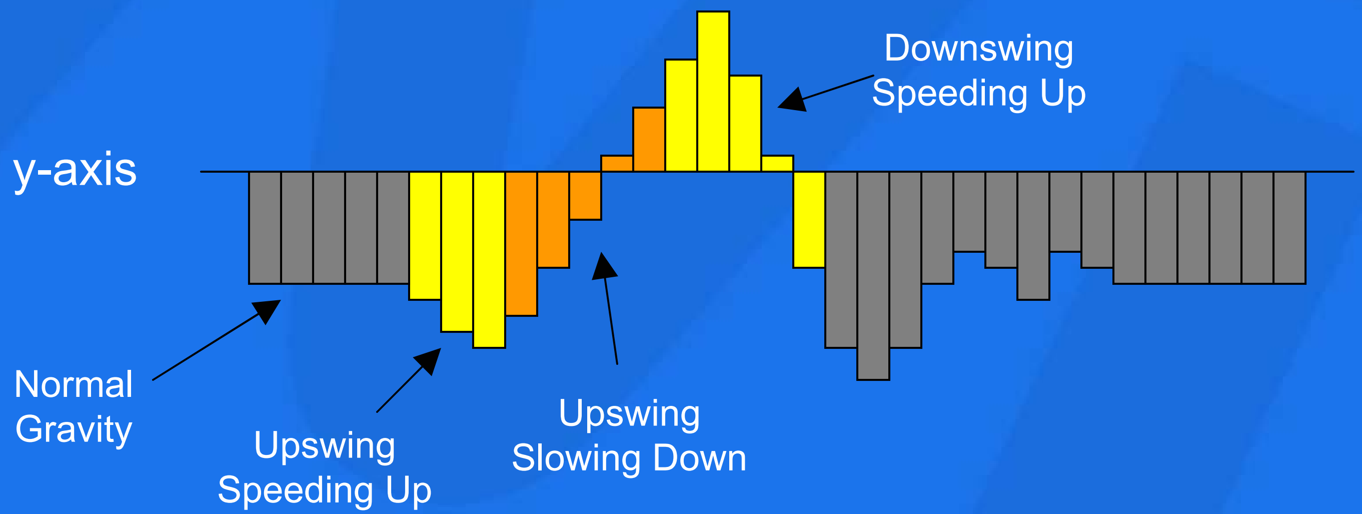
Drum Hit—Case Study #2

- Study up/down acceleration



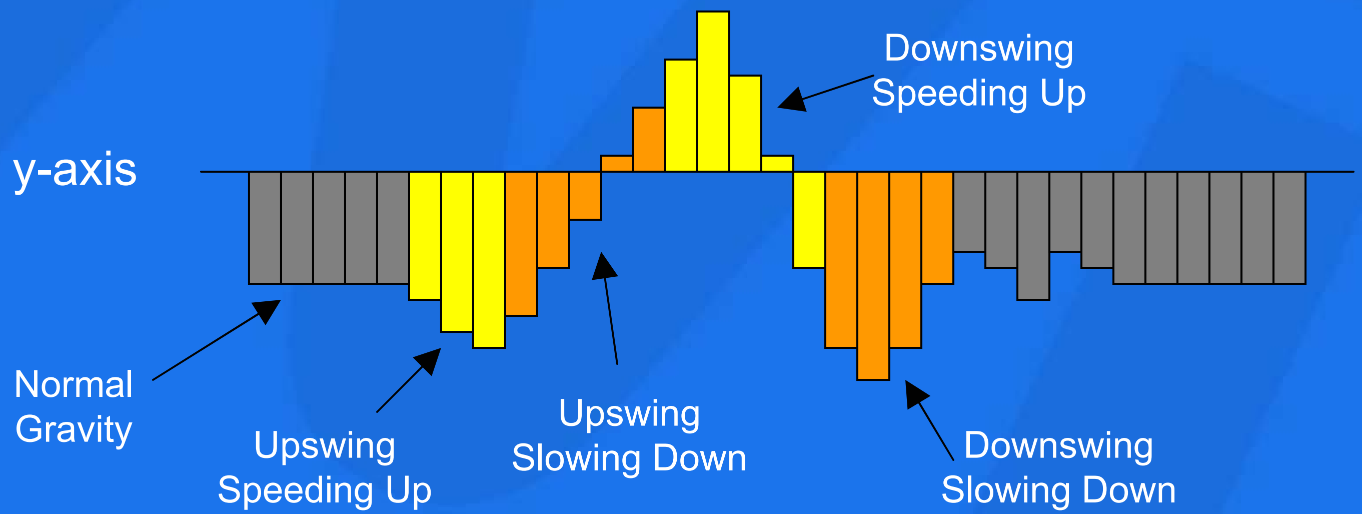
Drum Hit—Case Study #2

- Study up/down acceleration



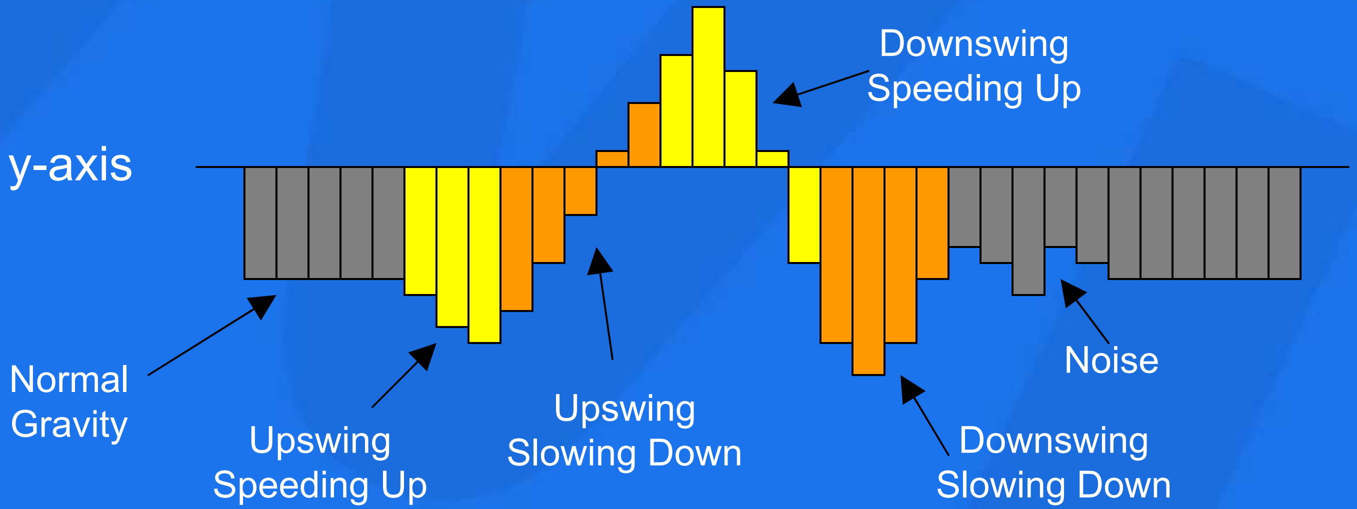
Drum Hit—Case Study #2

- Study up/down acceleration



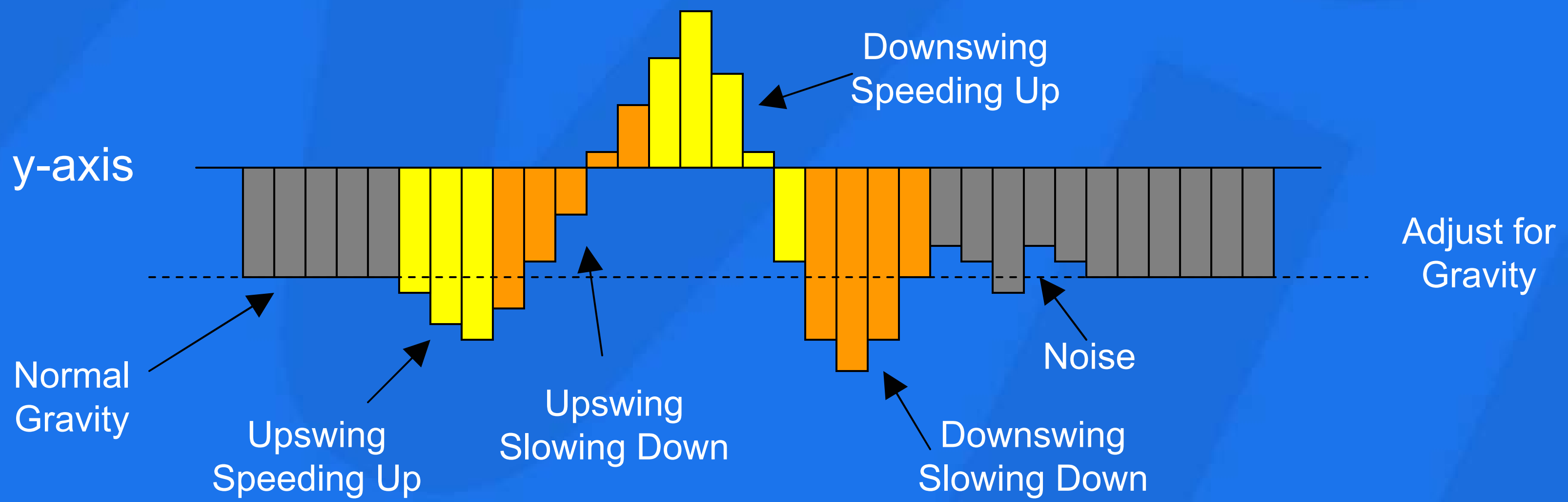
Drum Hit—Case Study #2

- Study up/down acceleration



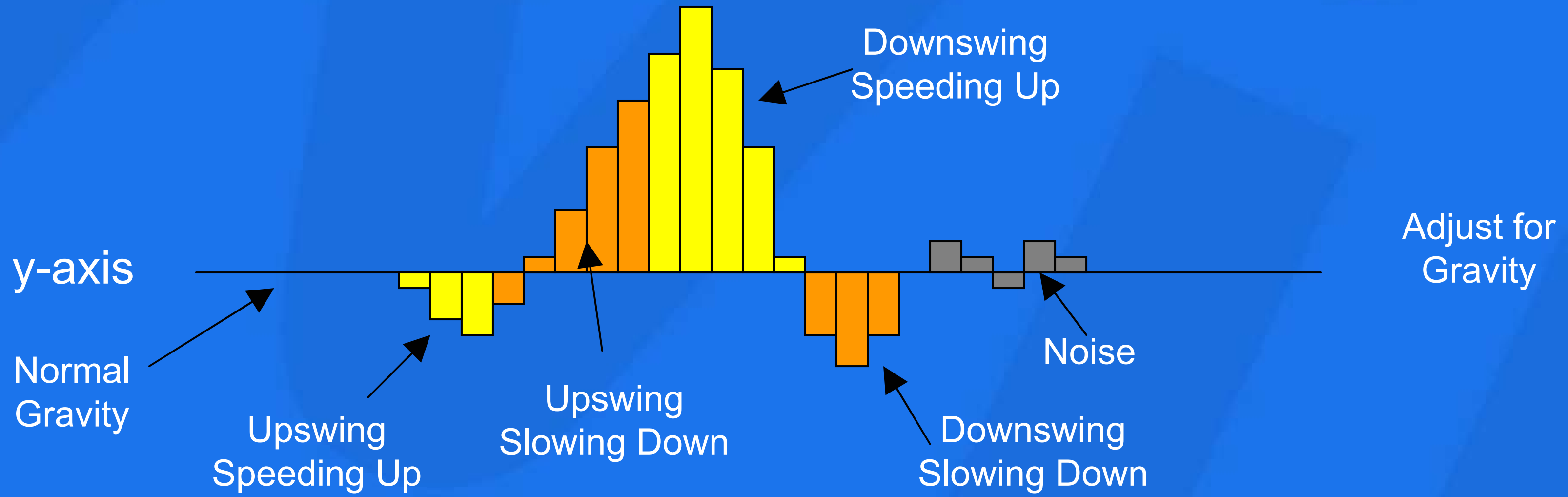
Drum Hit—Case Study #2

- Adjust values for gravity



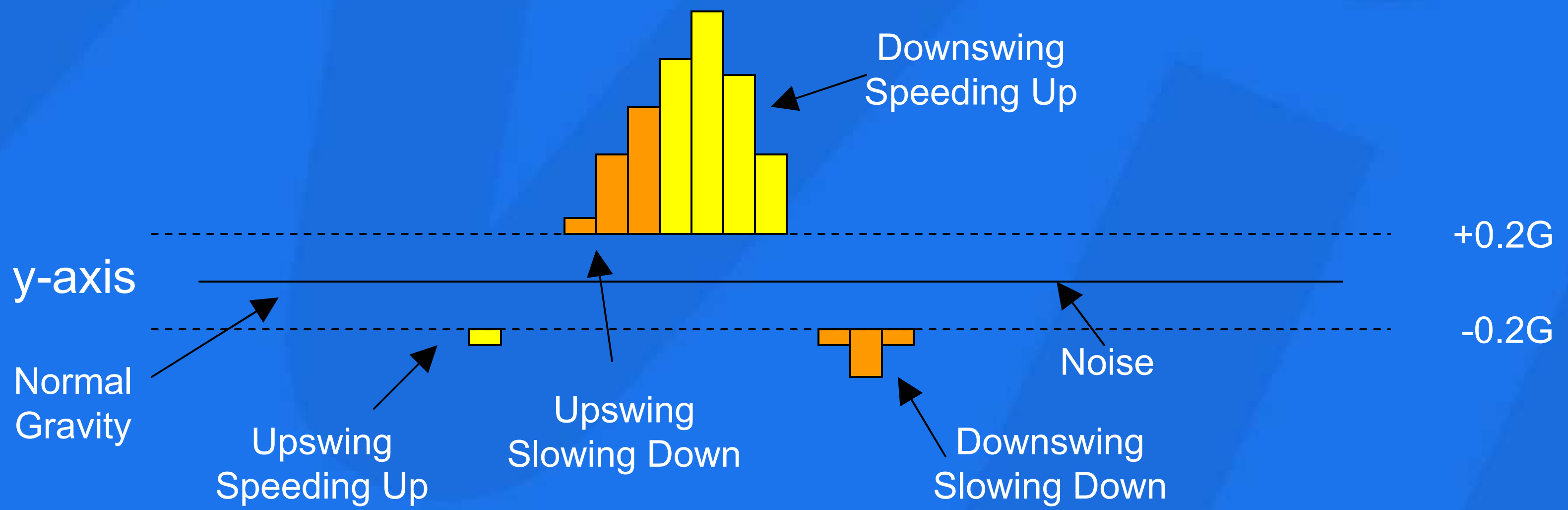
Drum Hit—Case Study #2

- Adjust values for gravity



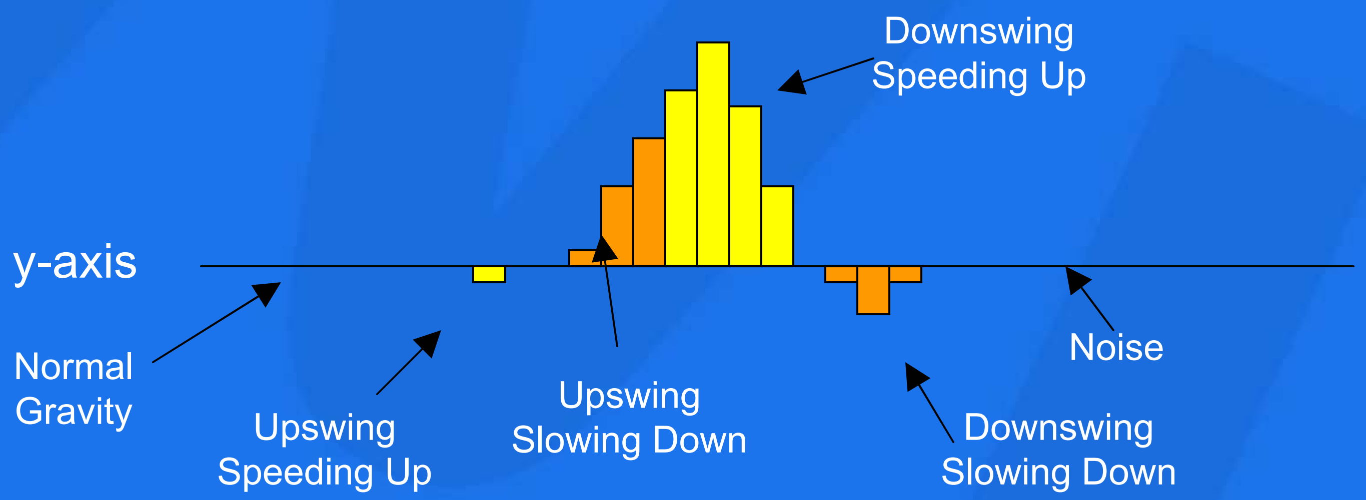
Drum Hit—Case Study #2

- Cut out values near zero



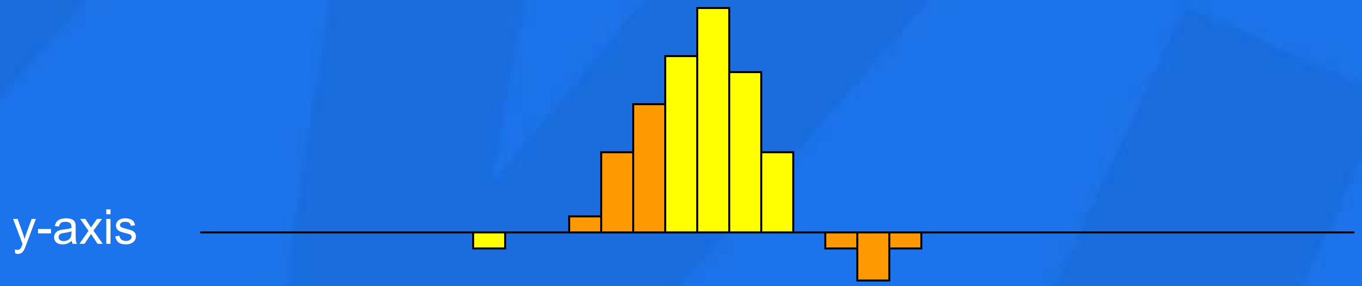
Drum Hit—Case Study #2

- Collapse values toward zero



Drum Hit—Case Study #2

- Pretend this acceleration is position!

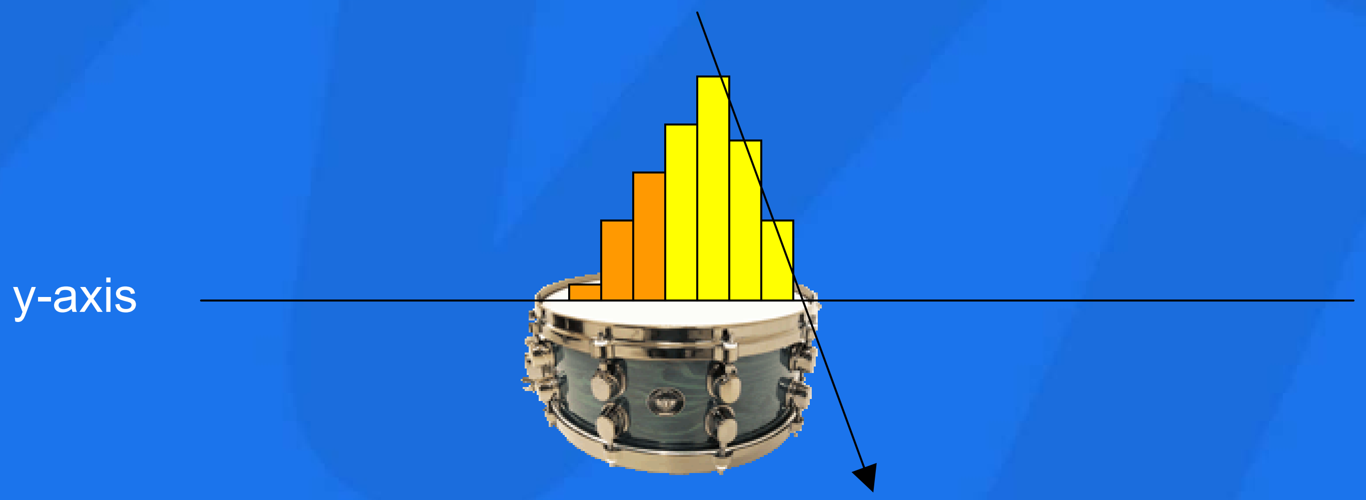


Drum Hit—Case Study #2

- Don't let drumstick go through drum

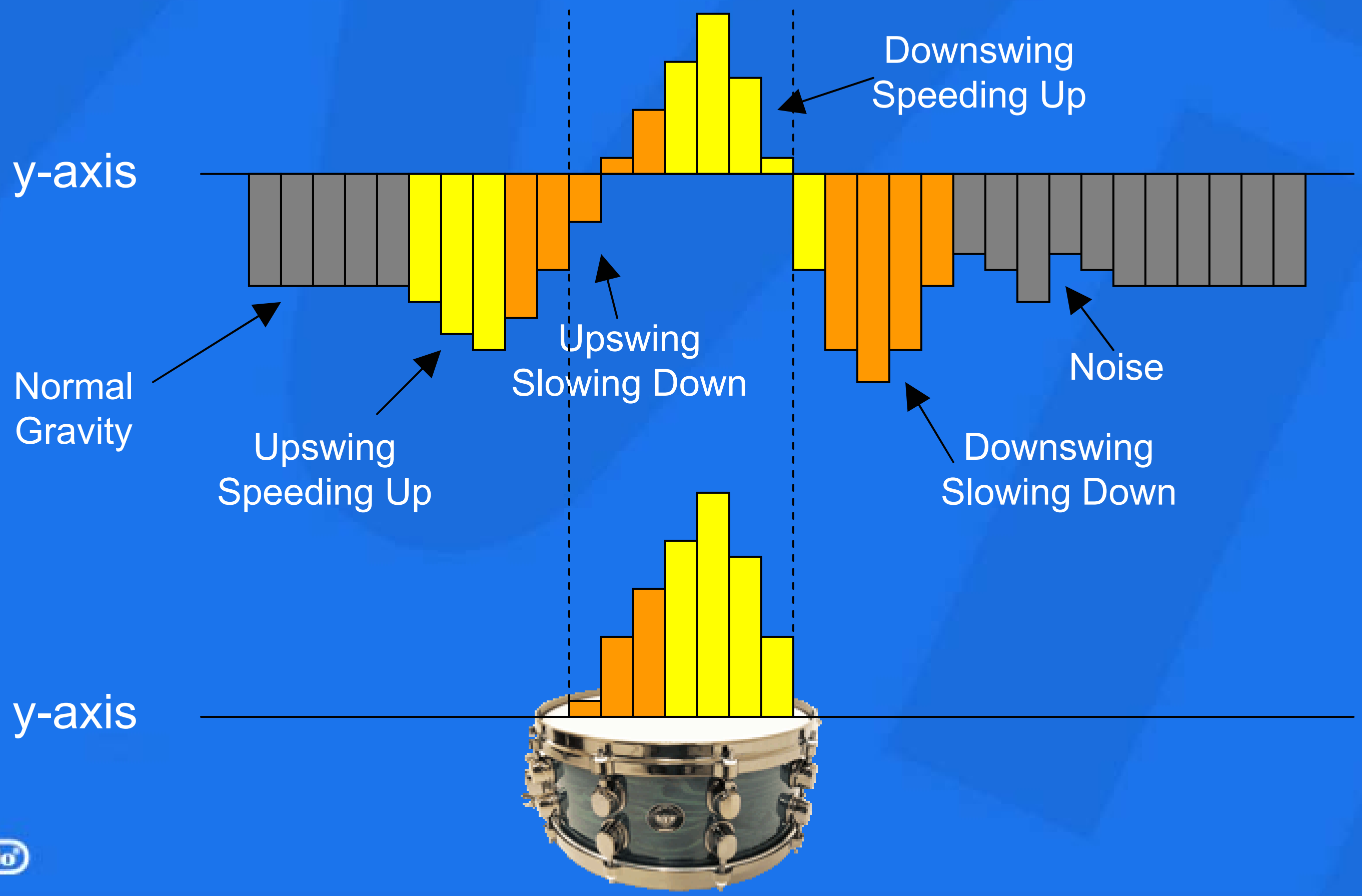
Drum Hit—Case Study #2

- Use derivative of position as velocity (loudness)



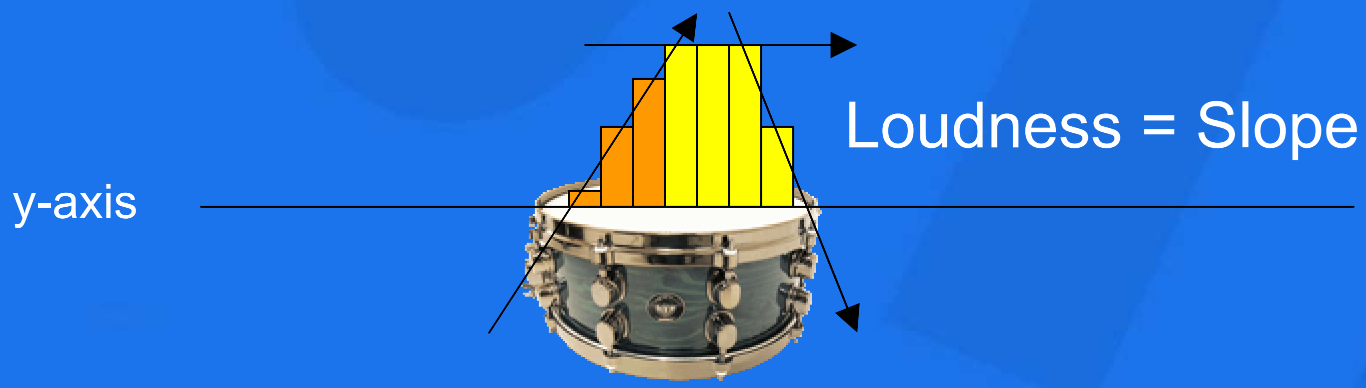
Drum Hit—Case Study #2

- Compare to original motion



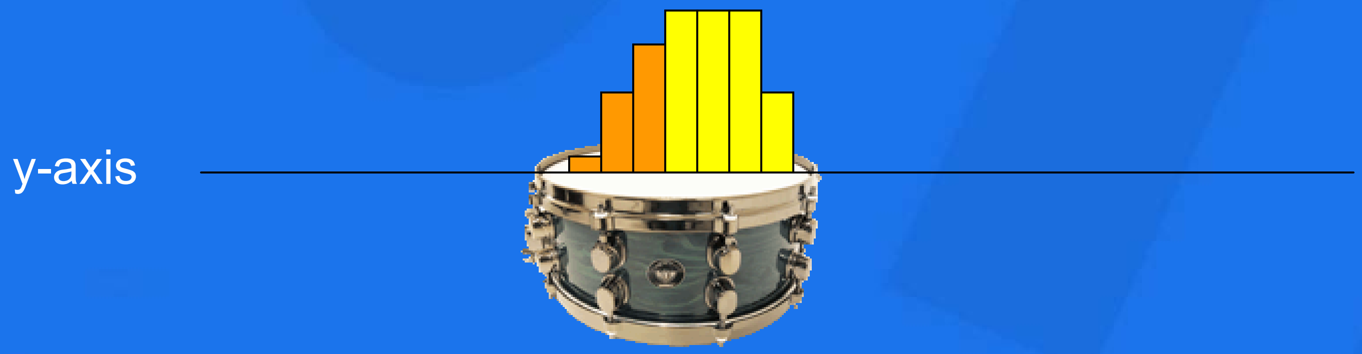
Drum Hit—Case Study #2

- What looks wrong about this?
  - Motion not smooth (in first derivative) – cartoonish
    - Upward/downward swing starts moving instantaneously
    - Abrupt stop at top (accelerometer limits)
  - Loudness is correlated with Wii Remote motion, but inaccurate (since actually derivative of acceleration)



Drum Hit—Case Study #2

- Summary
  - Acceleration as position works in limited situations
  - Must constrain from going in the wrong direction
  - Works OK for drum hits and boxing (but cartoonish)



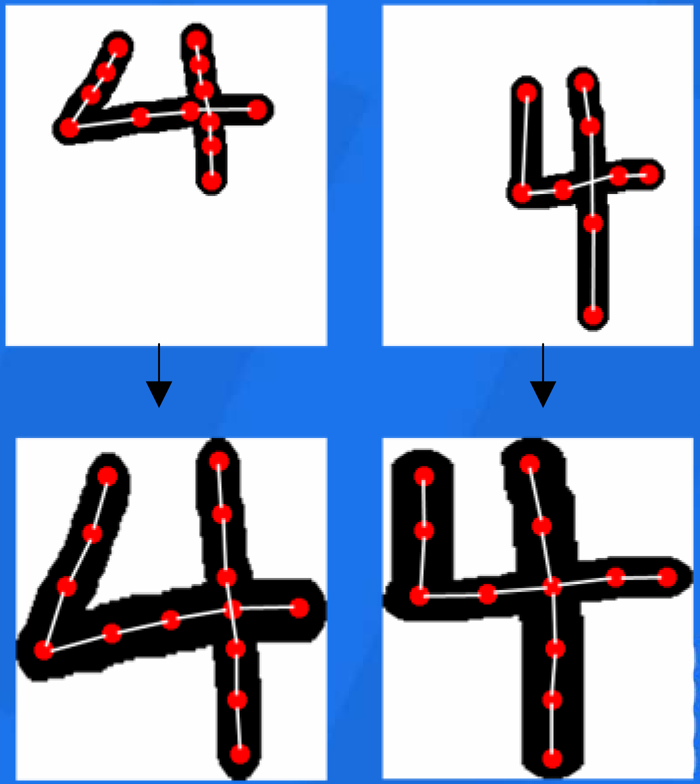
Complex Gesture Recognition: Five Techniques

Nintendo

Wii SUMMIT 2008

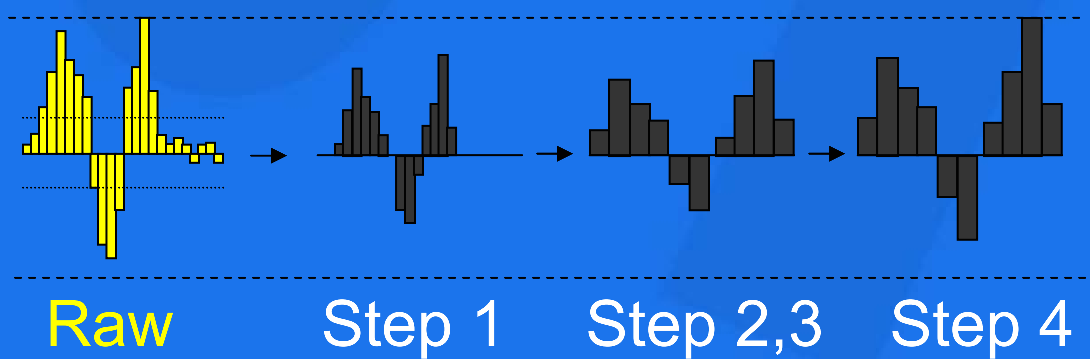
Complex Gesture Recognition: Preprocessing the Signal

- Example from handwriting recognition
  - Normalize size
  - Normalize length/speed



Complex Gesture Recognition: First Step—Preprocessing

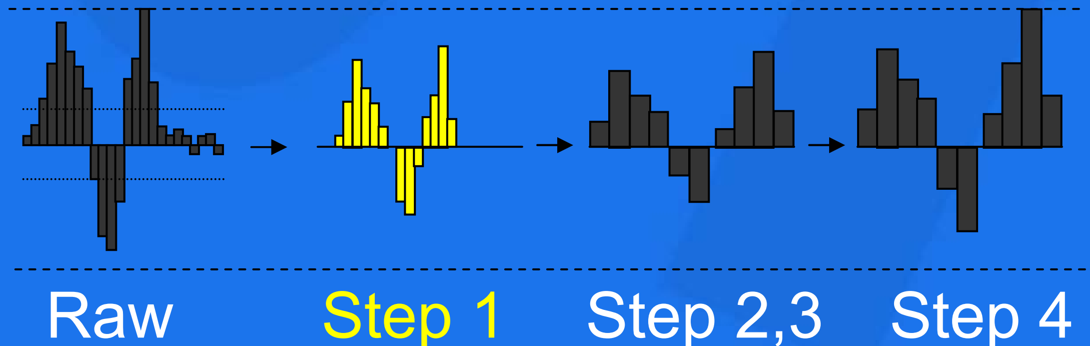
Massage input to look consistent/uniform



Complex Gesture Recognition: First Step—Preprocessing

Massage input to look consistent/uniform

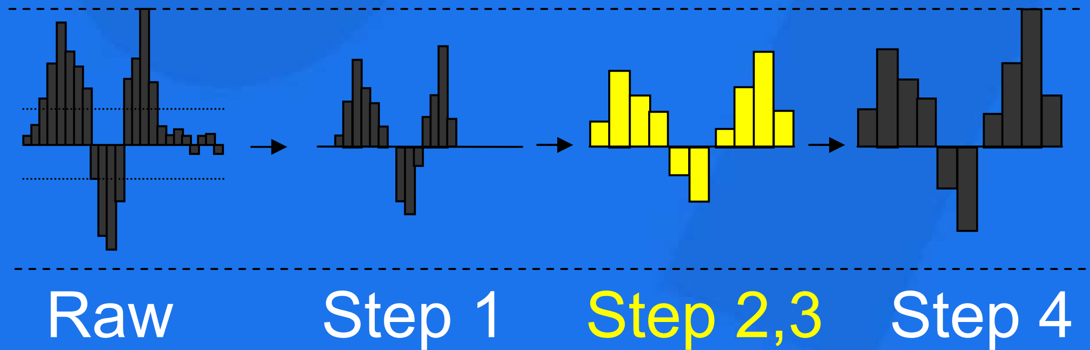
1. (optional) Remove gravity from all axes
   - Gravity problematic
   - Removes small movement noise



Complex Gesture Recognition: First Step—Preprocessing

Massage input to look consistent/uniform

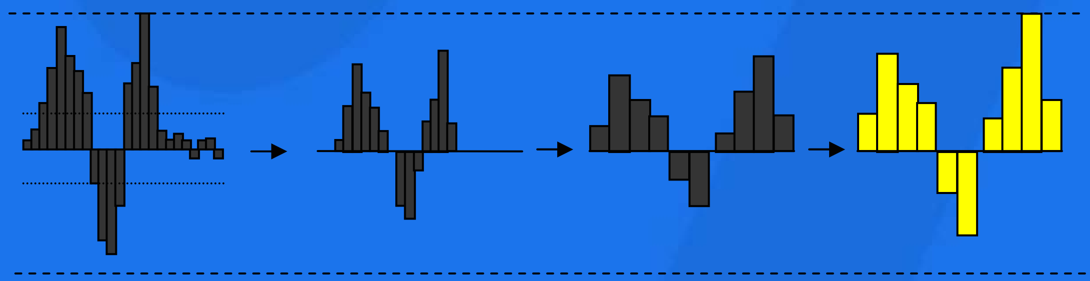
1. (optional) Remove gravity from all axes
   - Gravity problematic
   - Removes small movement noise
2. Remove parts with no acceleration
3. Normalize length



Complex Gesture Recognition: First Step—Preprocessing

Massage input to look consistent/uniform

1. (optional) Remove gravity from all axes
   - Gravity problematic
   - Removes small movement noise
2. Remove parts with no acceleration
3. Normalize length
4. Normalize intensity



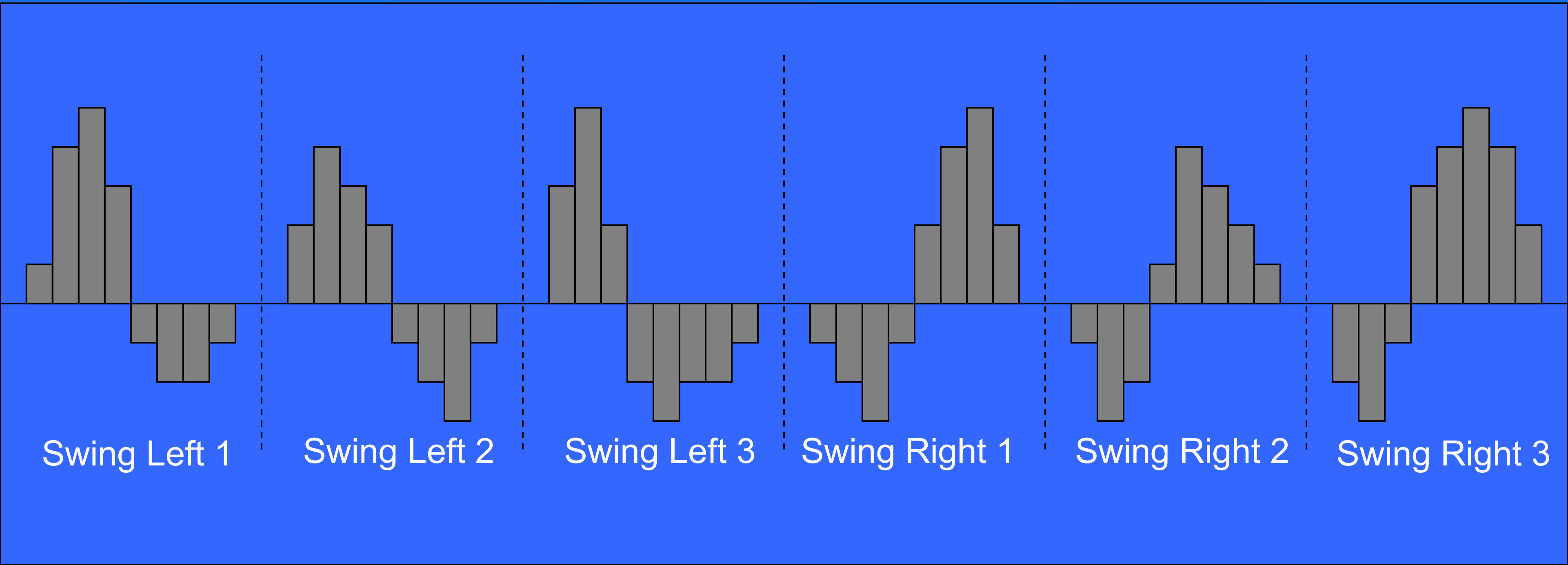
Raw Step 1 Step 2,3 Step 4

Nintendo

Wii SUMMIT 2008

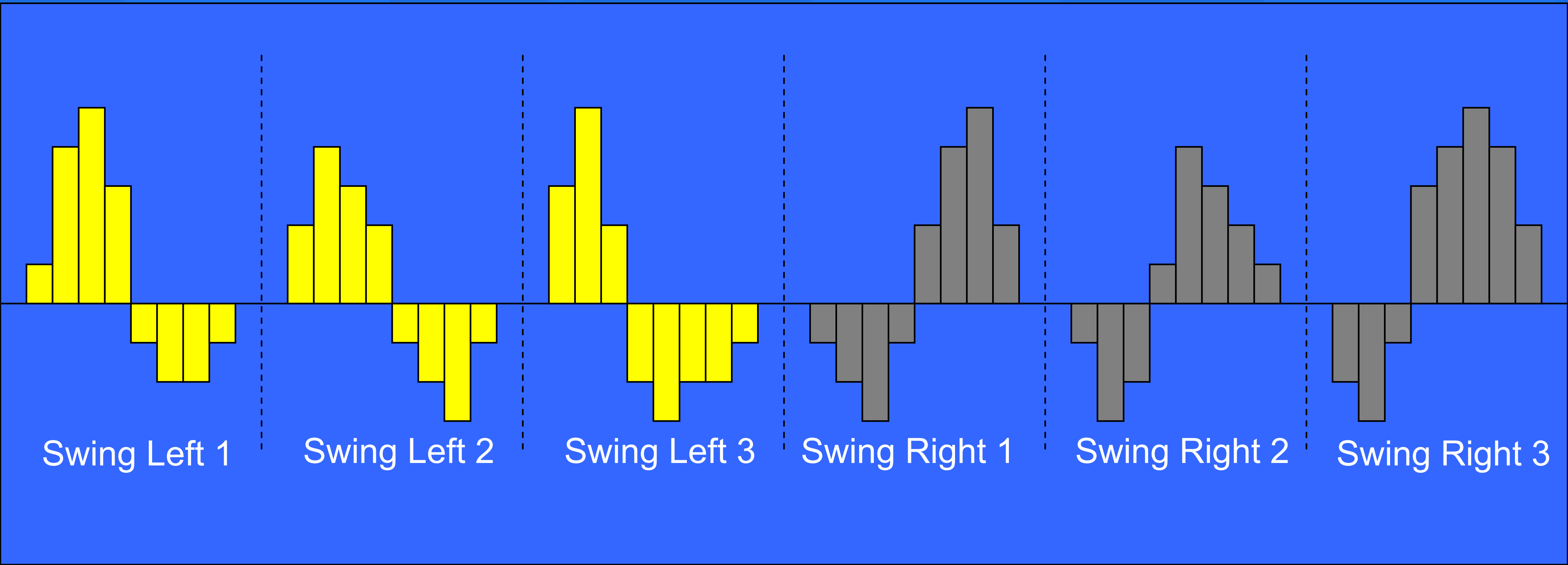
Complex Gesture Recognition: Technique 1—Nearest Neighbor

- Compare player input to database of examples



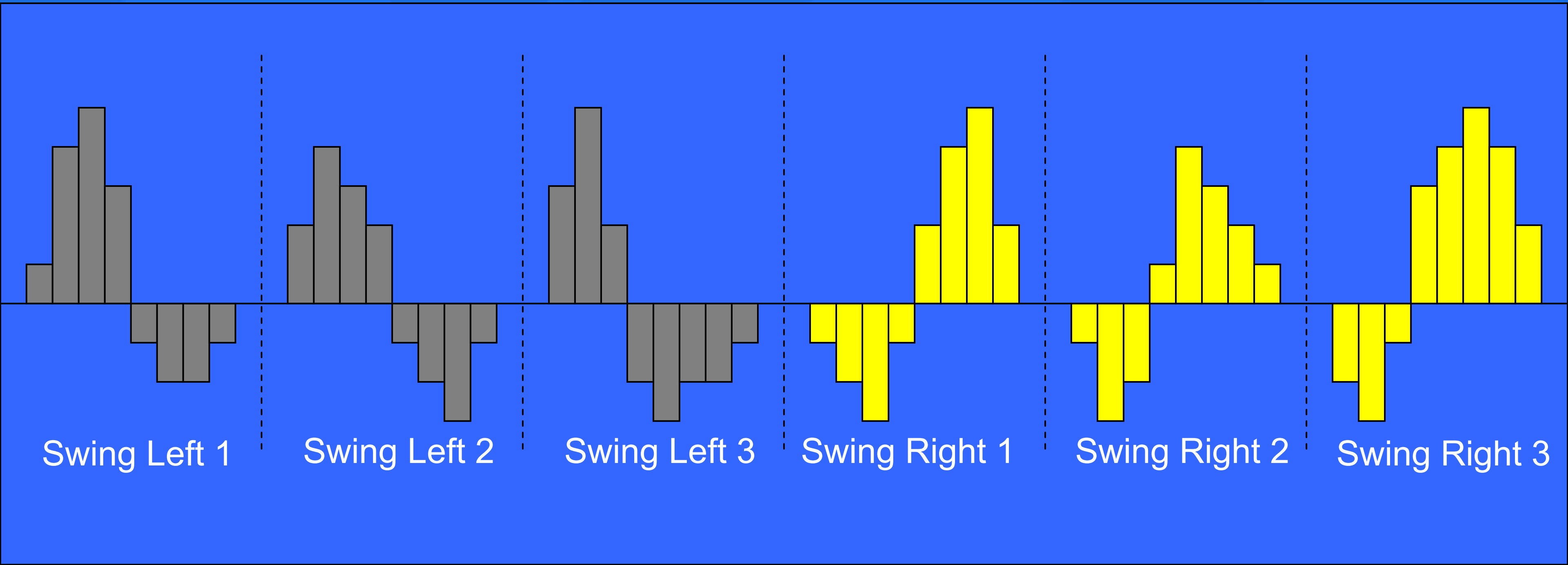
Complex Gesture Recognition: Technique 1—Nearest Neighbor

- Compare player input to database of examples



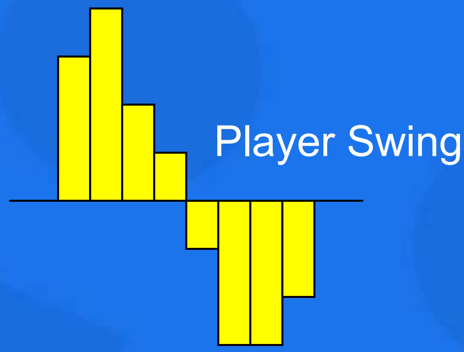
Complex Gesture Recognition: Technique 1—Nearest Neighbor

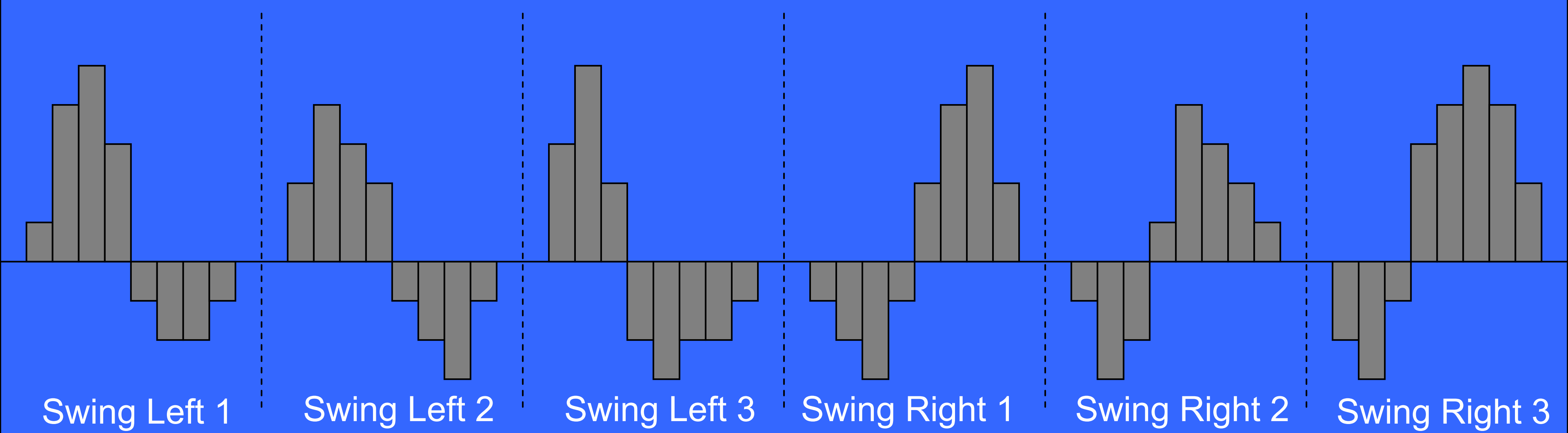
- Compare player input to database of examples



Complex Gesture Recognition: Technique 1—Nearest Neighbor

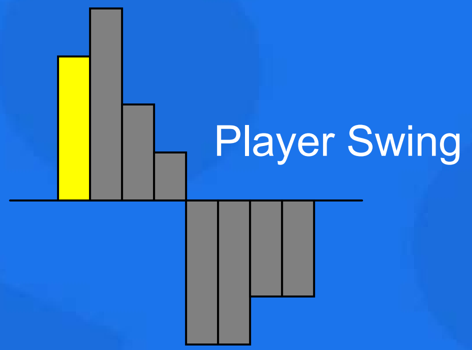
- Compare player input to database of examples

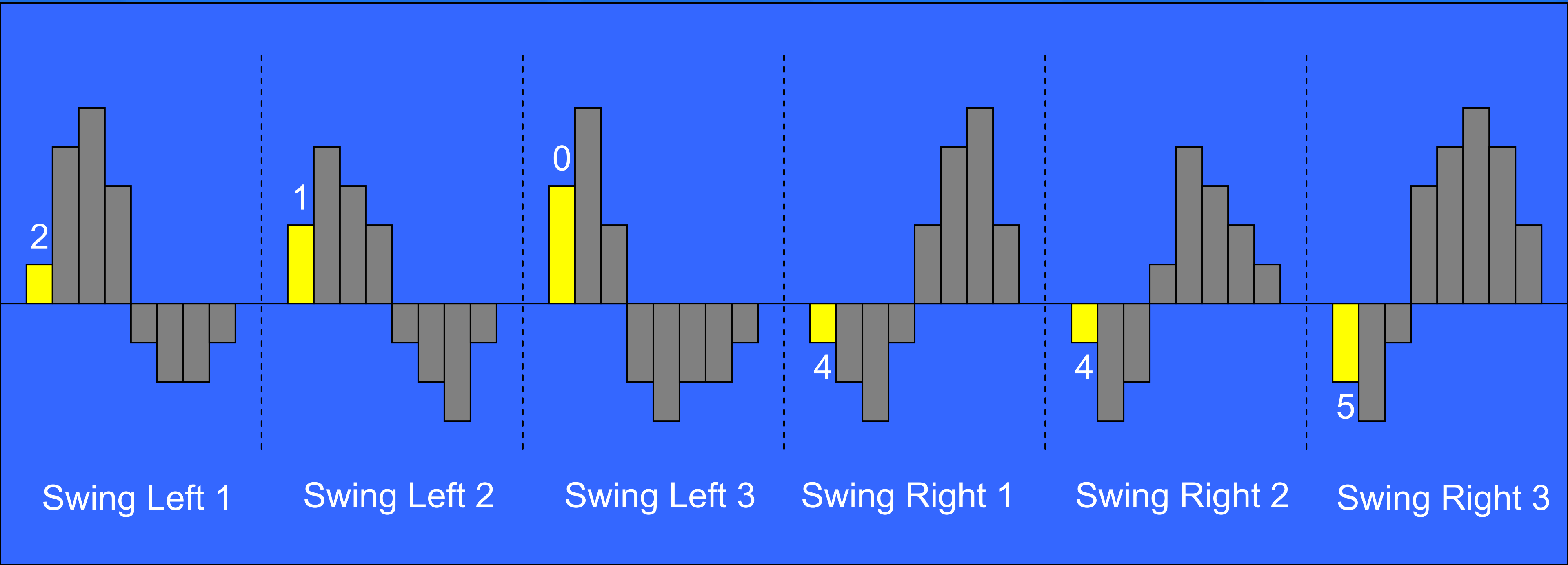




Complex Gesture Recognition: Technique 1—Nearest Neighbor

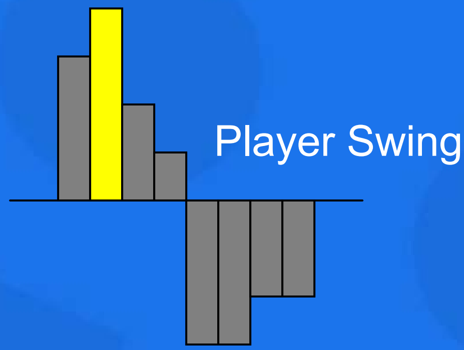
- Compare player input to database of examples
- Lowest error is match

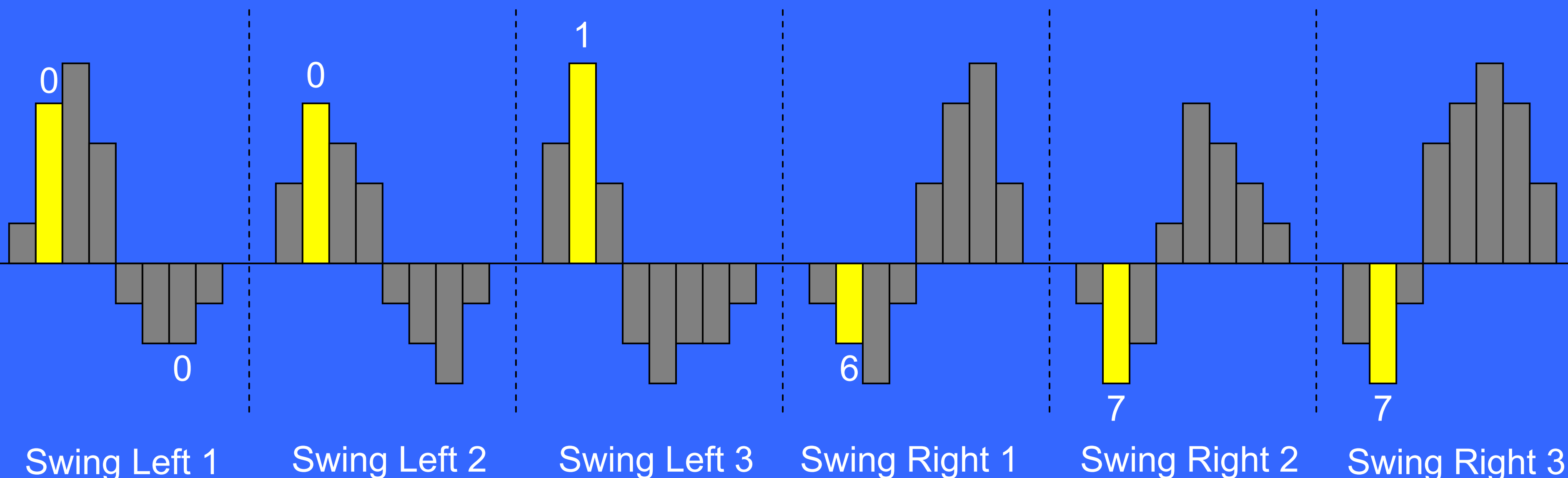




Complex Gesture Recognition: Technique 1—Nearest Neighbor

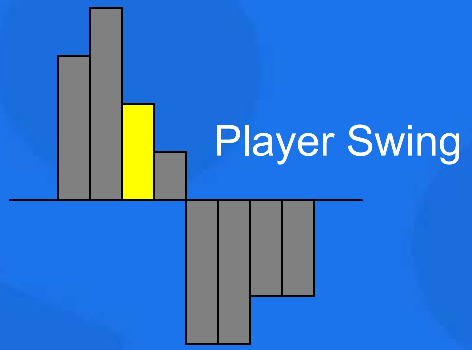
- Compare player input to database of examples
- Lowest error is match

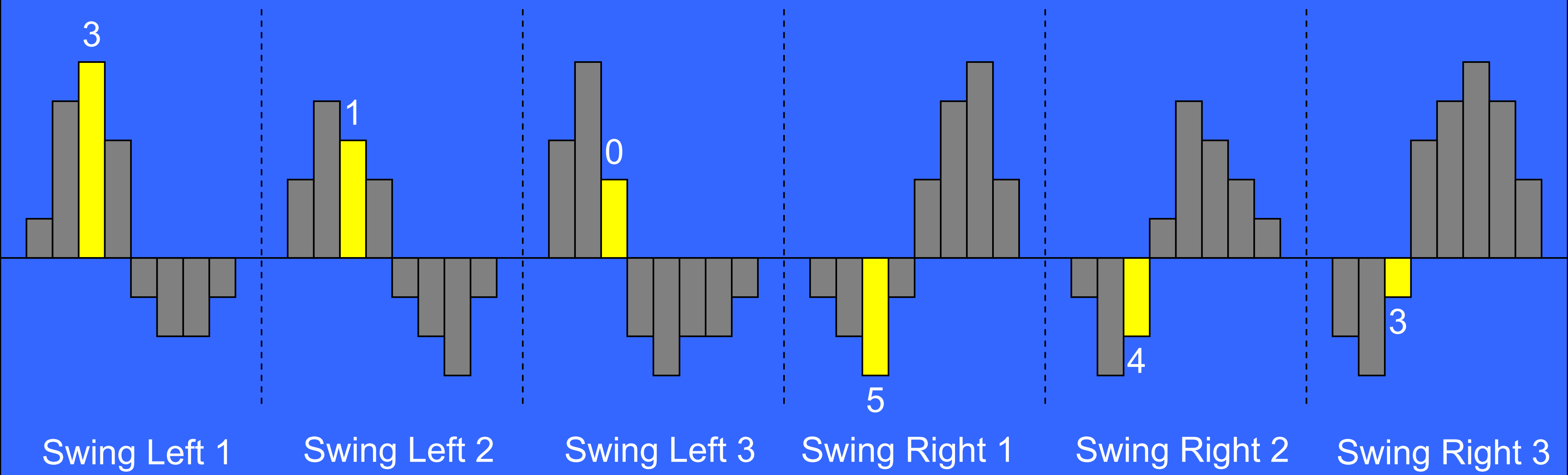




Complex Gesture Recognition: Technique 1—Nearest Neighbor

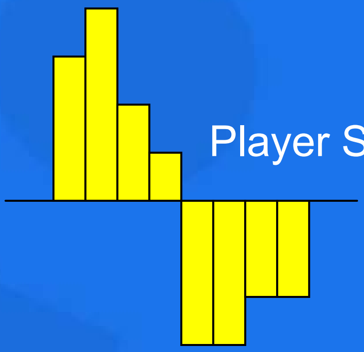
- Compare player input to database of examples
- Lowest error is match

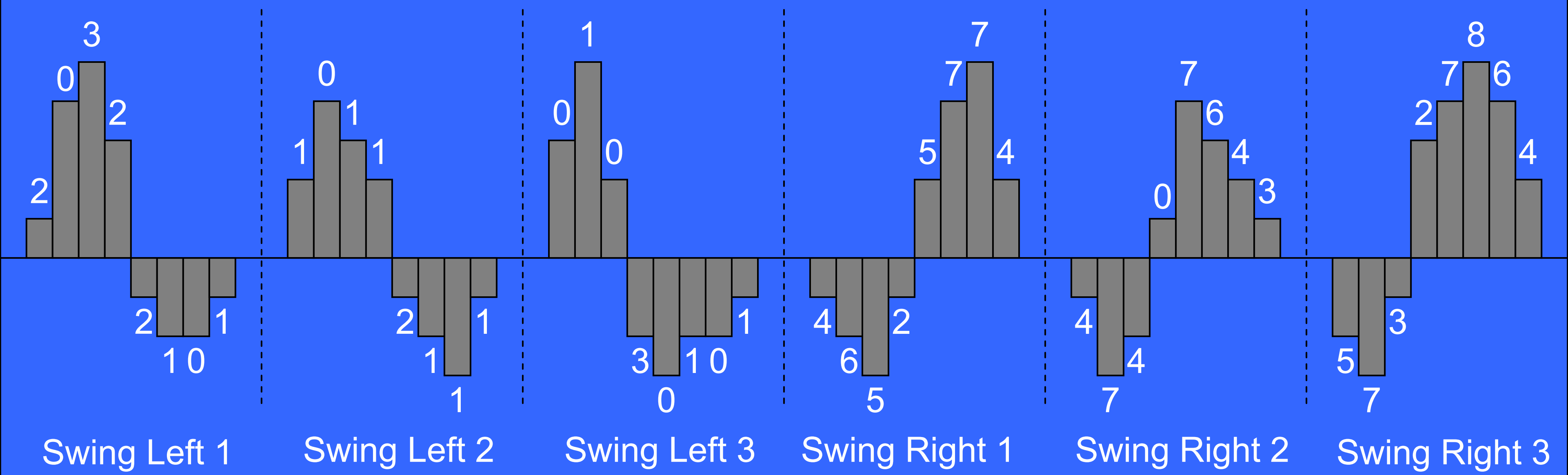




Complex Gesture Recognition: Technique 1—Nearest Neighbor

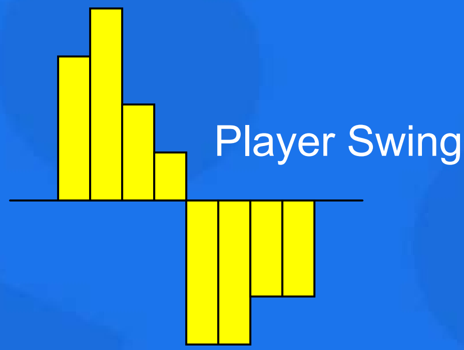
- Compare player input to database of examples
- Lowest error is match

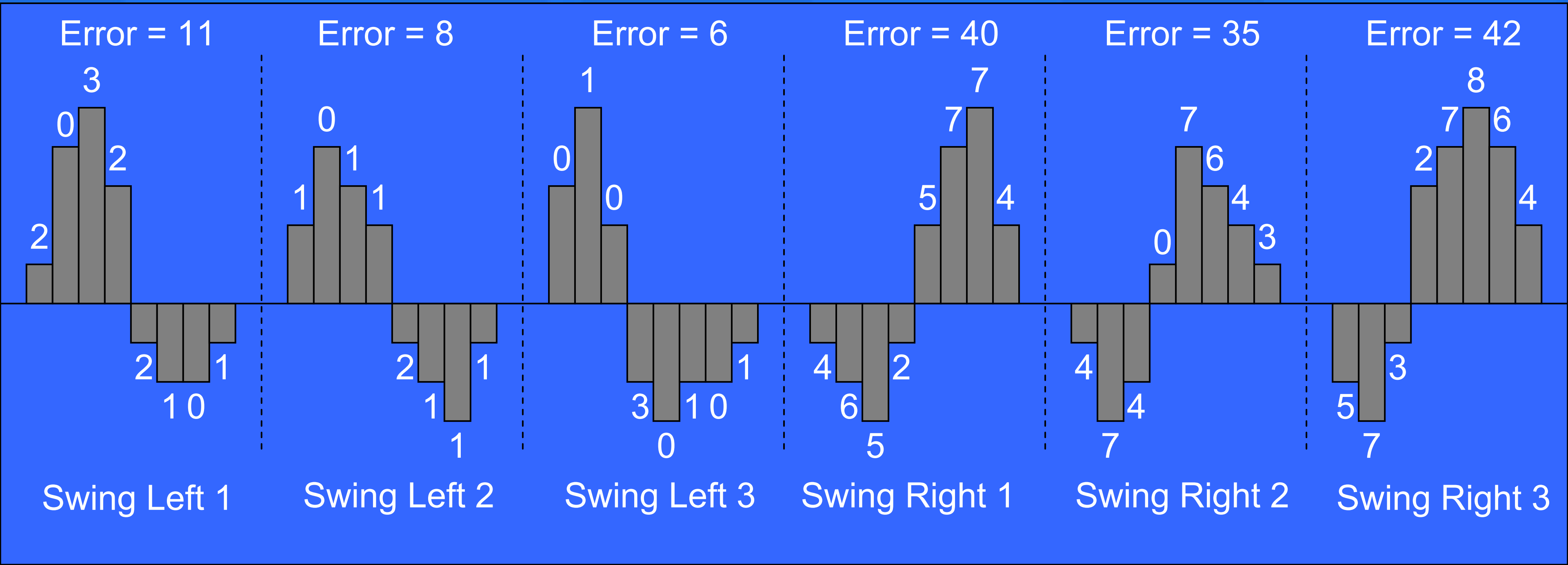




Complex Gesture Recognition: Technique 1—Nearest Neighbor

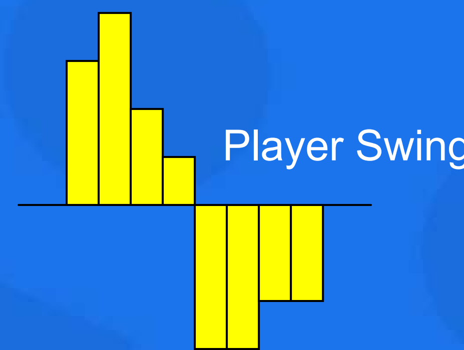
- Compare player input to database of examples
- Lowest error is match

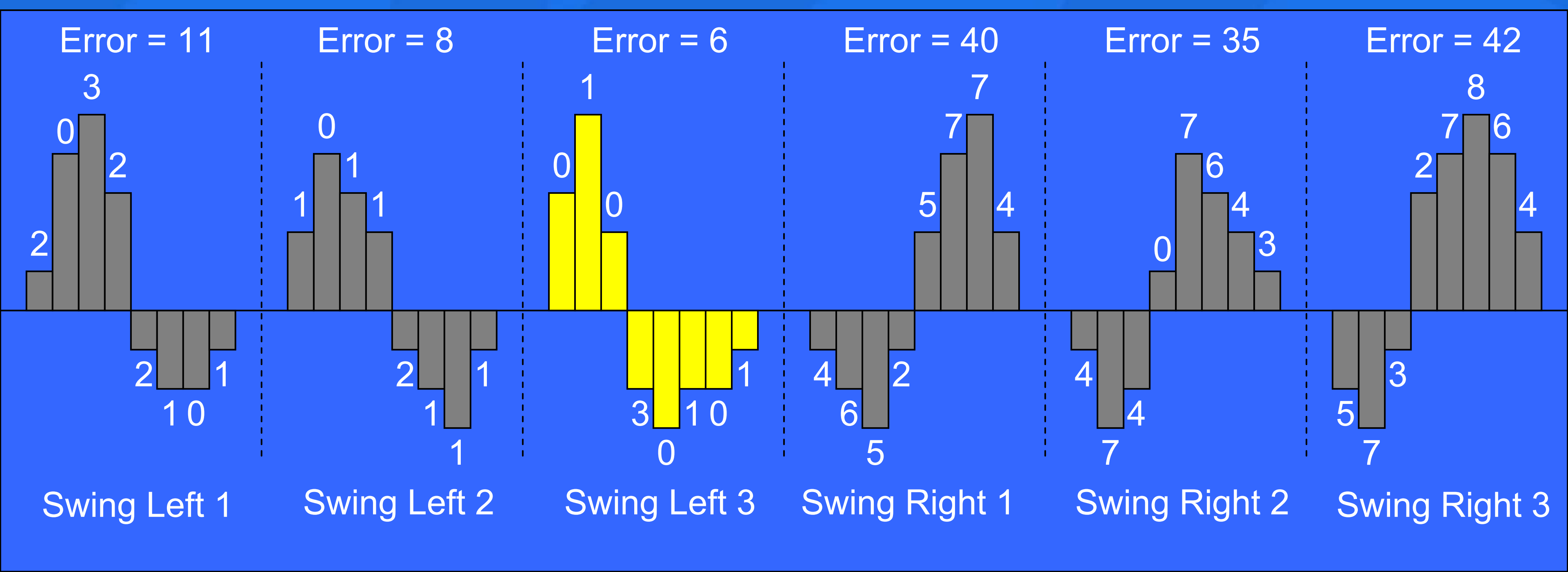




Complex Gesture Recognition: Technique 1—Nearest Neighbor

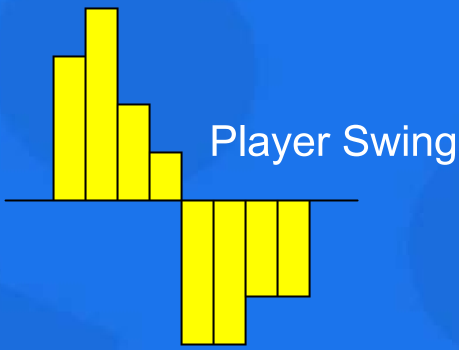
- Compare player input to database of examples
- Lowest error is match

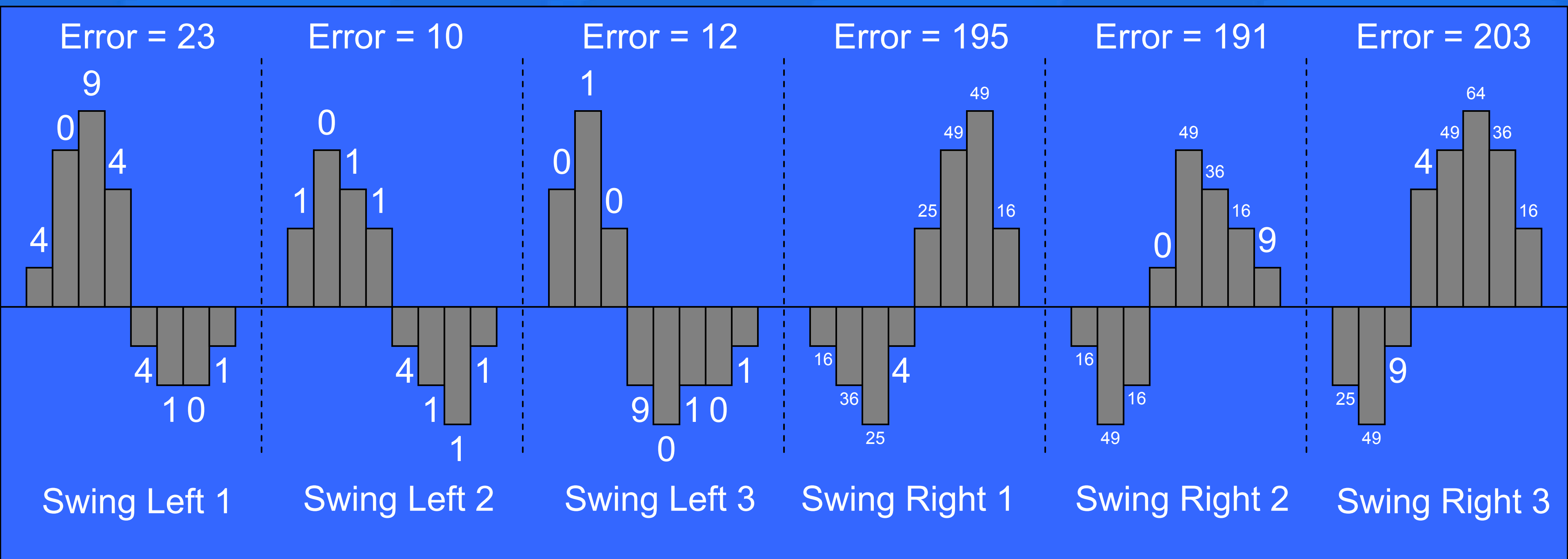




Complex Gesture Recognition: Technique 1—Nearest Neighbor

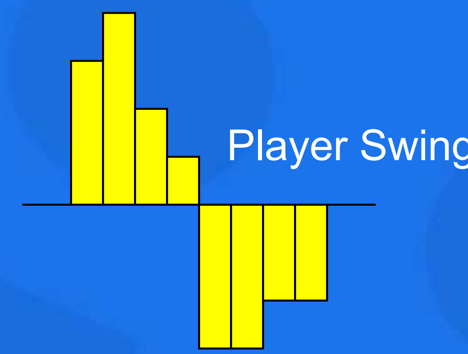
- Compare player input to database of examples
- Lowest error is match (ROOT MEAN SQUARE!)

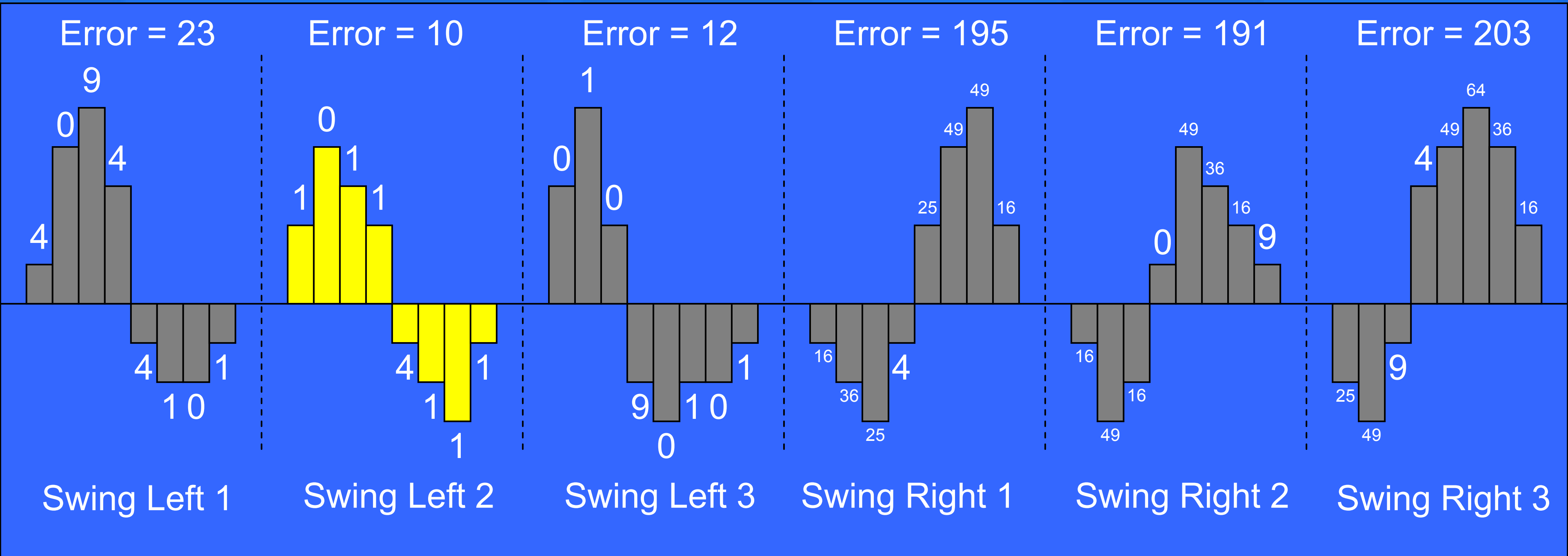




Complex Gesture Recognition: Technique 1—Nearest Neighbor

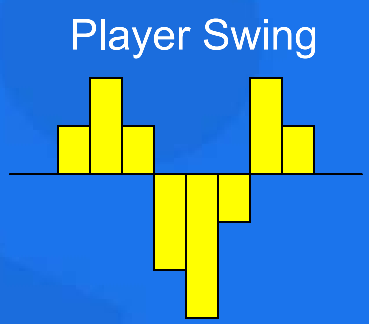
- Compare player input to database of examples
- Lowest error is match (ROOT MEAN SQUARE!)

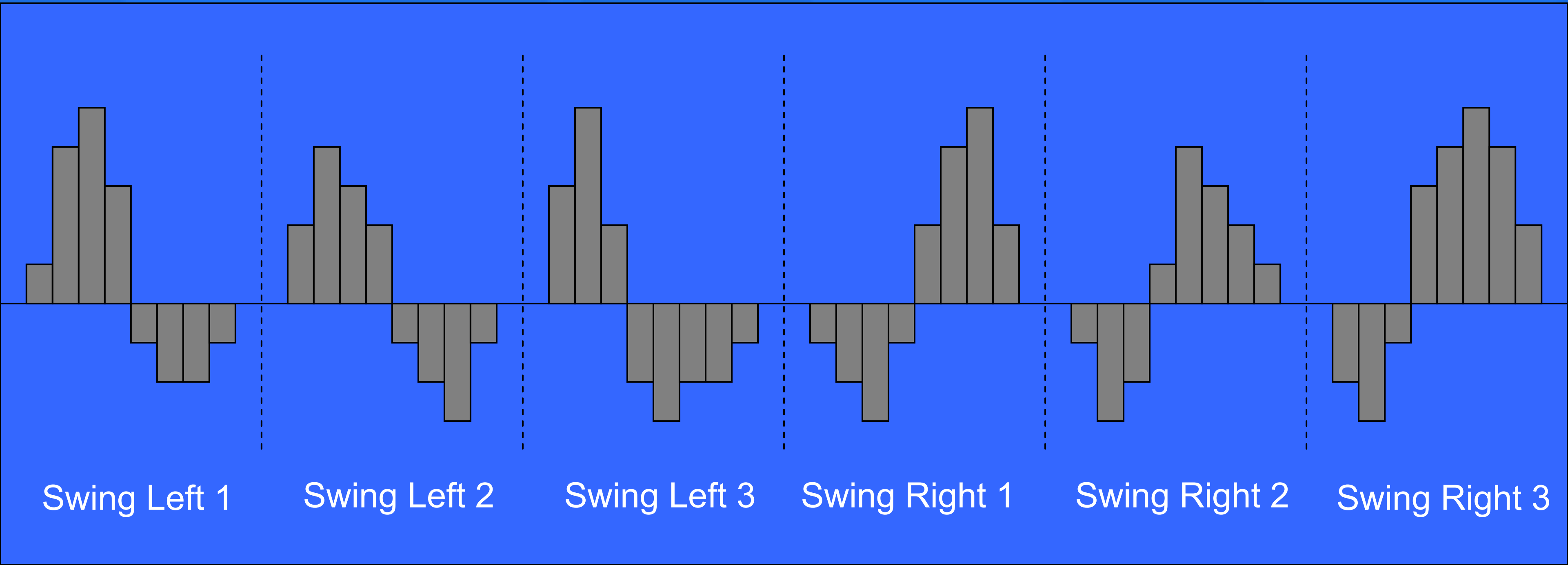




Complex Gesture Recognition: Technique 1—Nearest Neighbor

- Compare player input to database of examples
- Lowest error is match

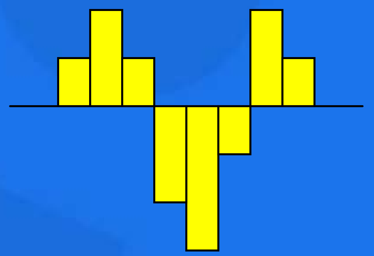


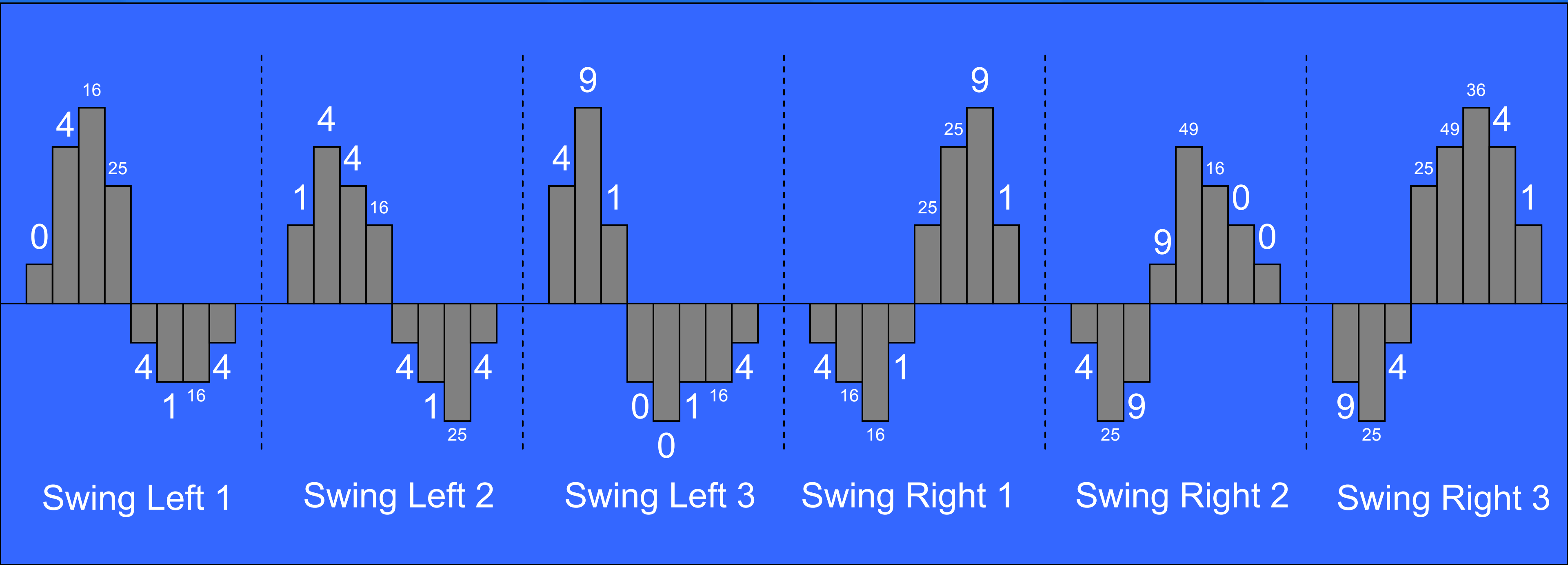


Complex Gesture Recognition: Technique 1—Nearest Neighbor

- Compare player input to database of examples
- Lowest error is match

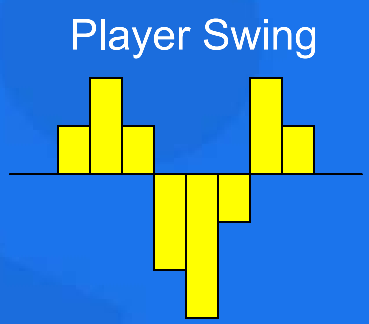
Player Swing

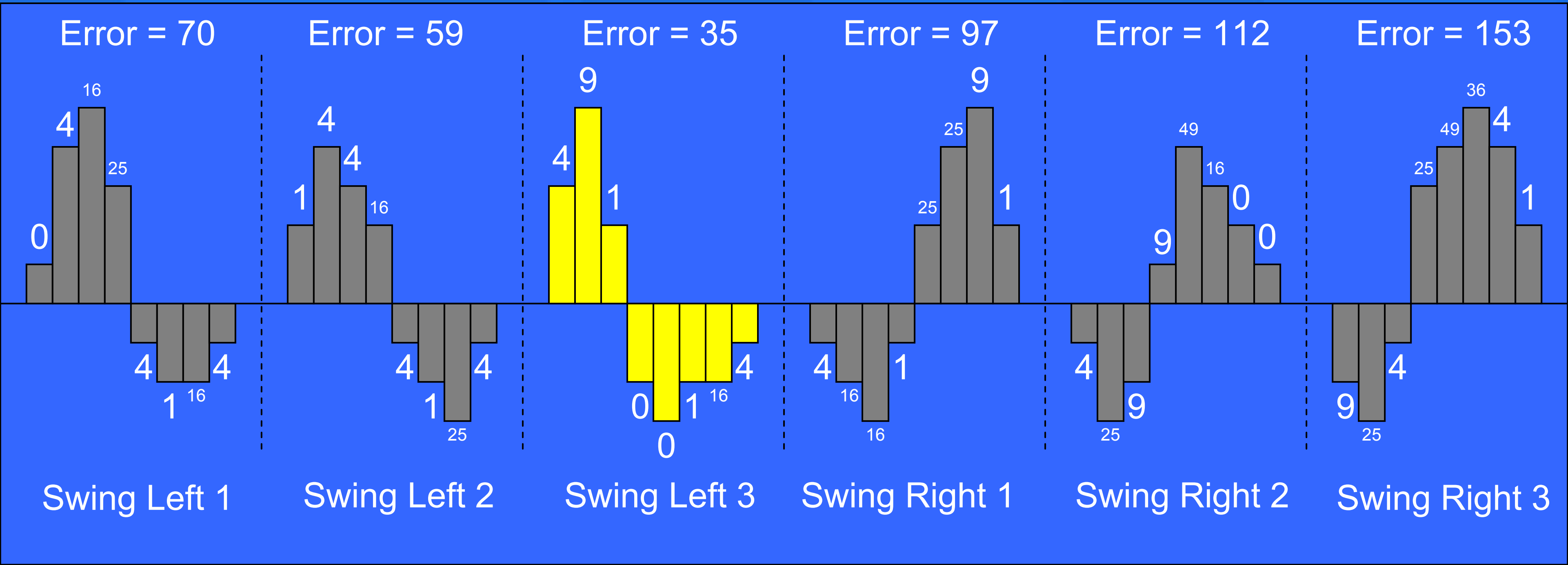




Complex Gesture Recognition: Technique 1—Nearest Neighbor

- Compare player input to database of examples
- Lowest error is match

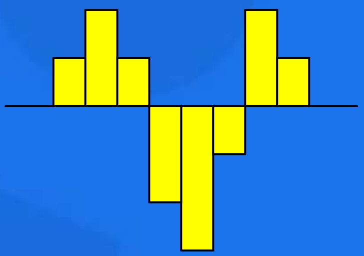


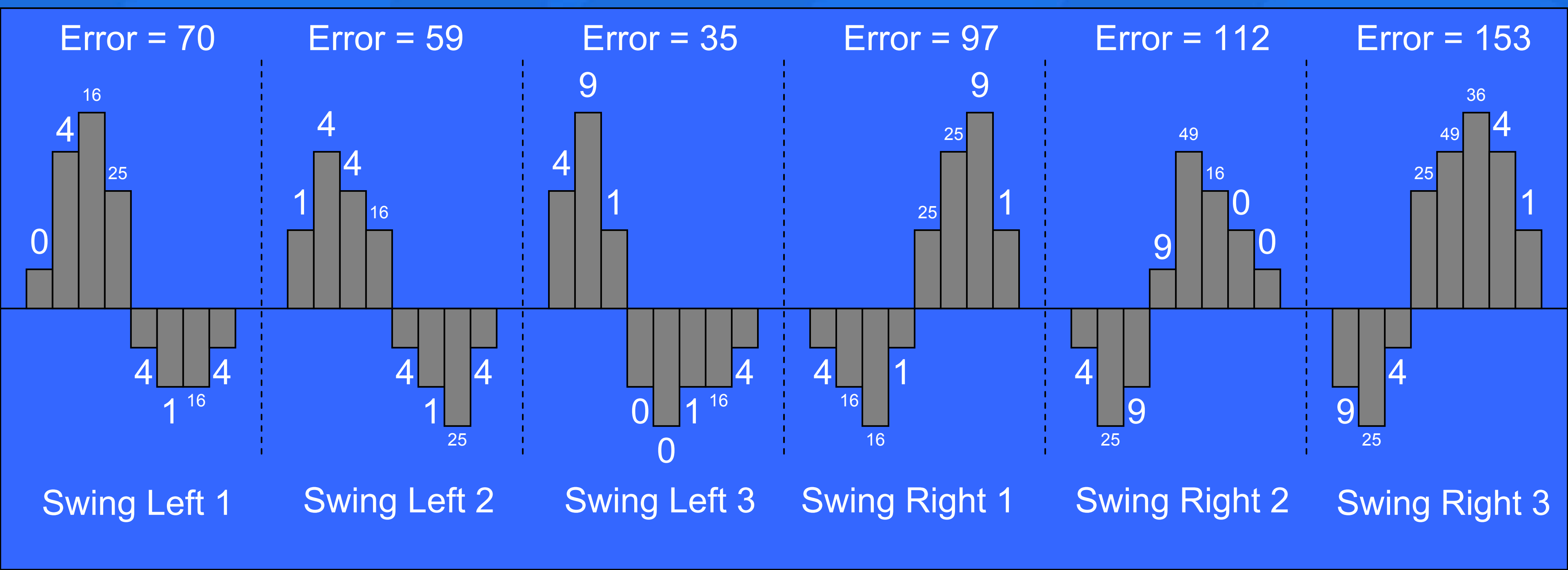


Complex Gesture Recognition: Technique 1—Nearest Neighbor

- Compare player input to database of examples
- Lowest error is match
- Large error = no match

Player Swing



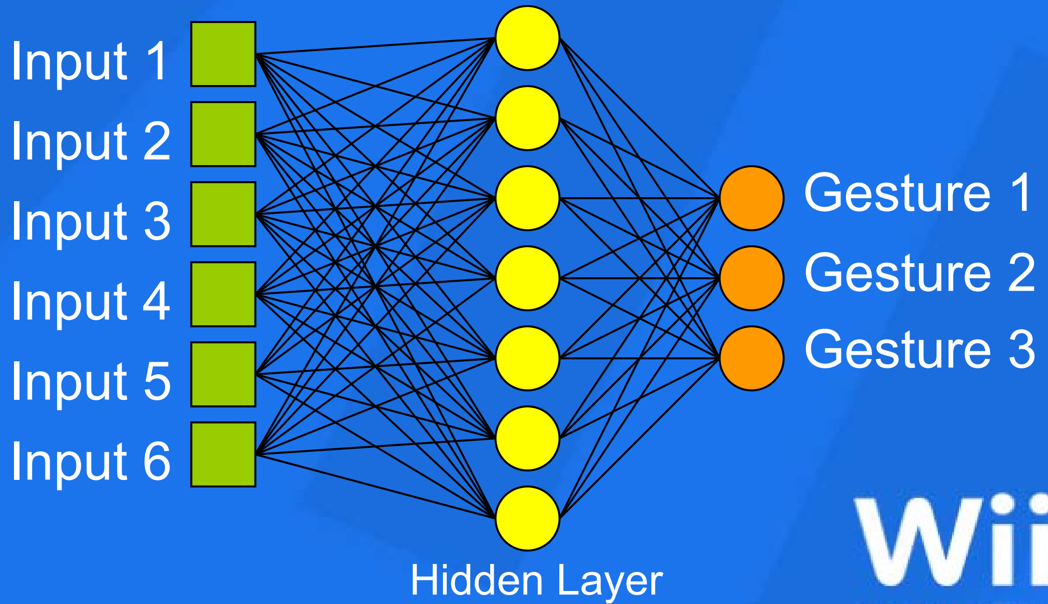


Complex Gesture Recognition: Technique 1—Nearest Neighbor

- General algorithm to match against database
  - Not many examples needed
  - Preprocess data for best matching
- Can constantly monitor input stream
- Player could supply examples

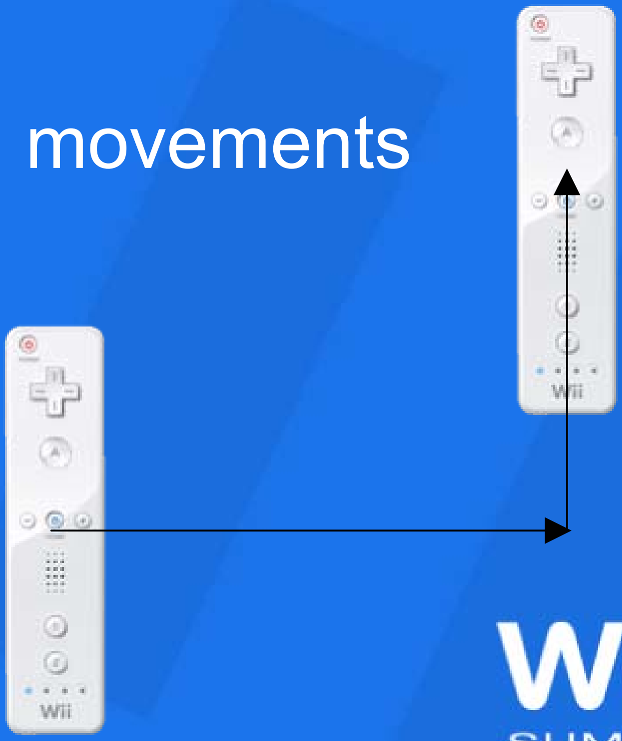
Complex Gesture Recognition: Technique 2—Neural Network

- Black box that tells you the answer
- You train it with 100s or 1000s of examples
  - Network generalizes to examples

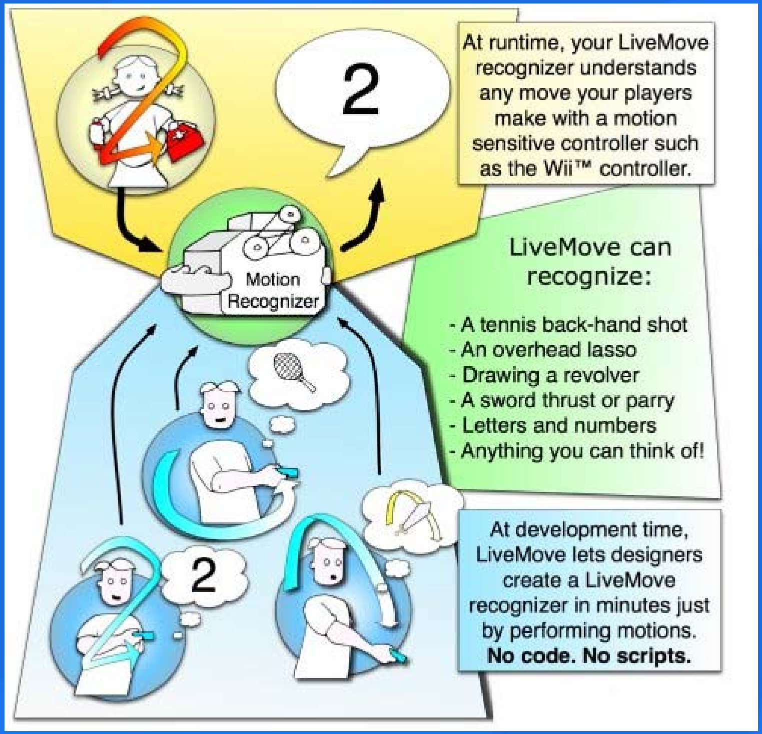


Complex Gesture Recognition: Technique 3—Cheat

- Adapt a complex gesture into a series of simple gestures
- Sequences of axis-aligned movements
  - Easier to detect
  - Train the player



Complex Gesture Recognition: Technique 4—LiveMove Middleware



www.ailive.net
support@ailive.net

Complex Gesture Recognition: Technique 5—Use your Brain

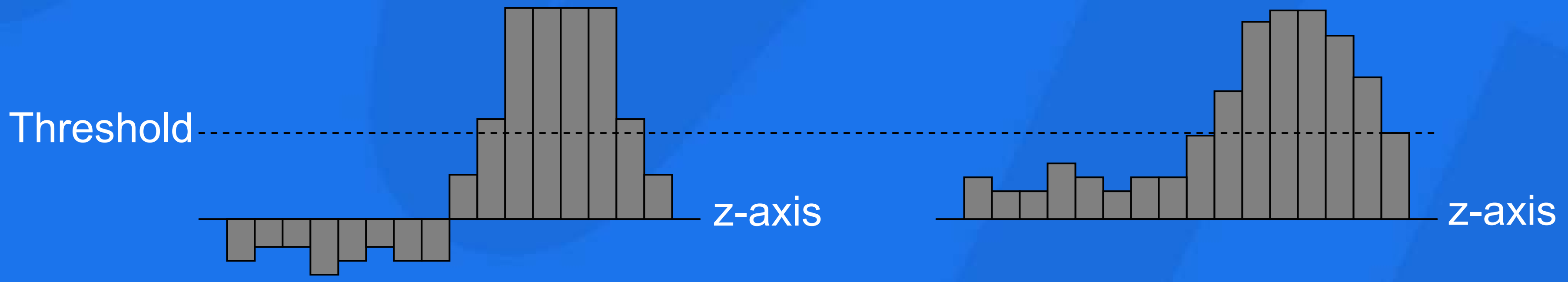
1. Study the move(s) you want to detect
2. Identify its features
   - Is there a single feature that is unique?
   - Is it consistent no matter who does the gesture?
3. Write custom detection code for the single gesture
   - Various threshold tests in sequence
   - Threshold triggering relative to other axes
4. Discern the differences between two gestures
   - In cases where it's one or the other

Complex Gesture Recognition:
Wii Sports Tennis Case Study

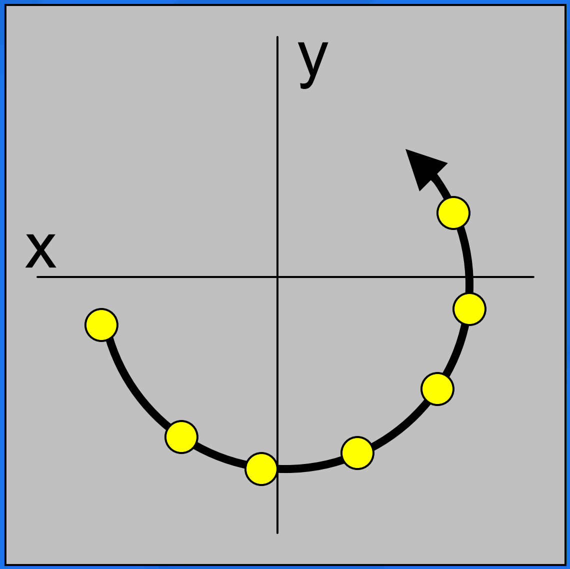
- Recognize any swing
- Recognize left or right swing
- Recognize topspin, backspin, no spin
- Recognize underhand or overhand
- Recognize hard or soft hit

Complex Gesture Recognition:
Recognize Swing

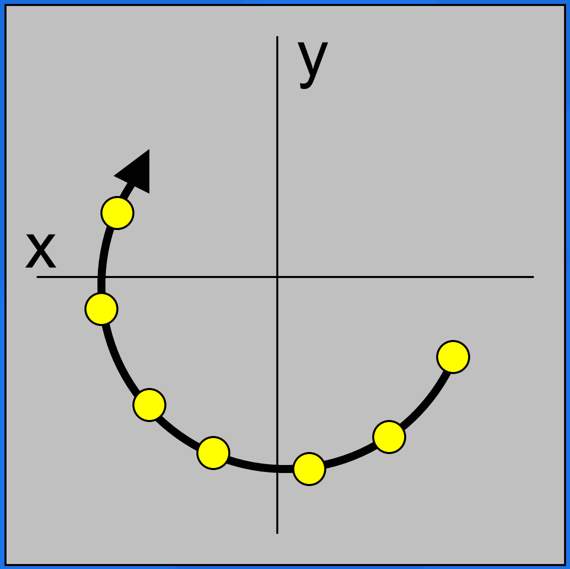
- Threshold on z-axis
  - Something like 1.2G to 1.5G



Complex Gesture Recognition:
Left or Right Swing



Left Swing
(counterclockwise)

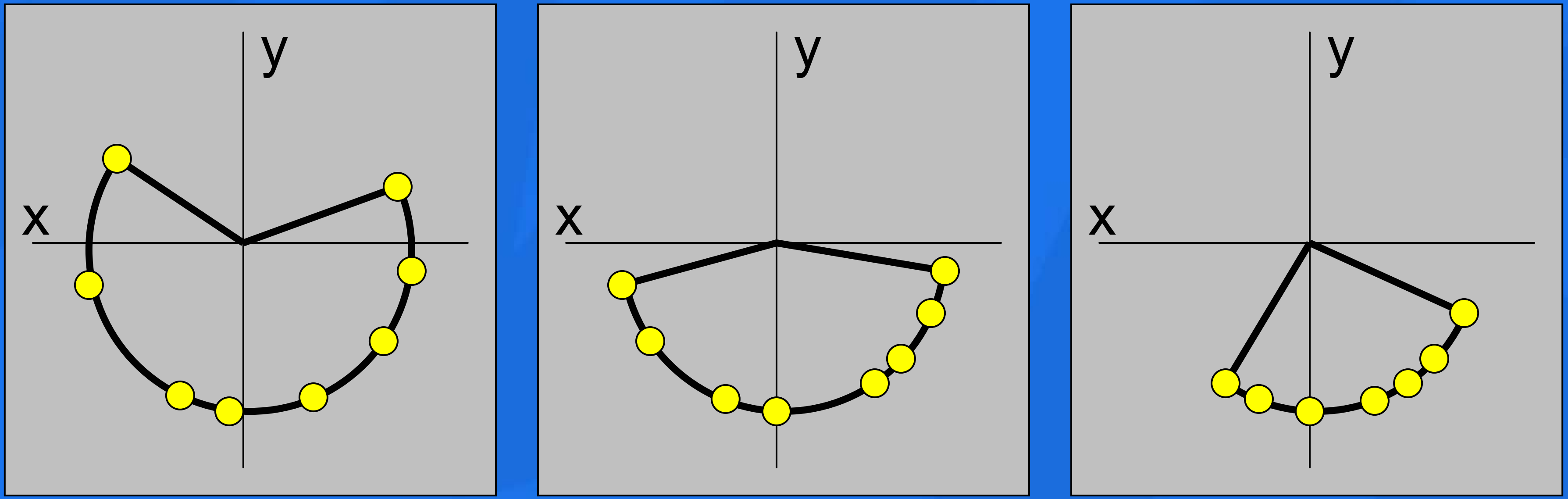


Right Swing
(clockwise)

Complex Gesture Recognition:
Left or Right Swing

- Orientation of controller doesn't matter!
- Increase recognition:
  - Predict correct swing
  - Make incorrect swings require larger threshold
    - Avoids mistaking "prep" as swing

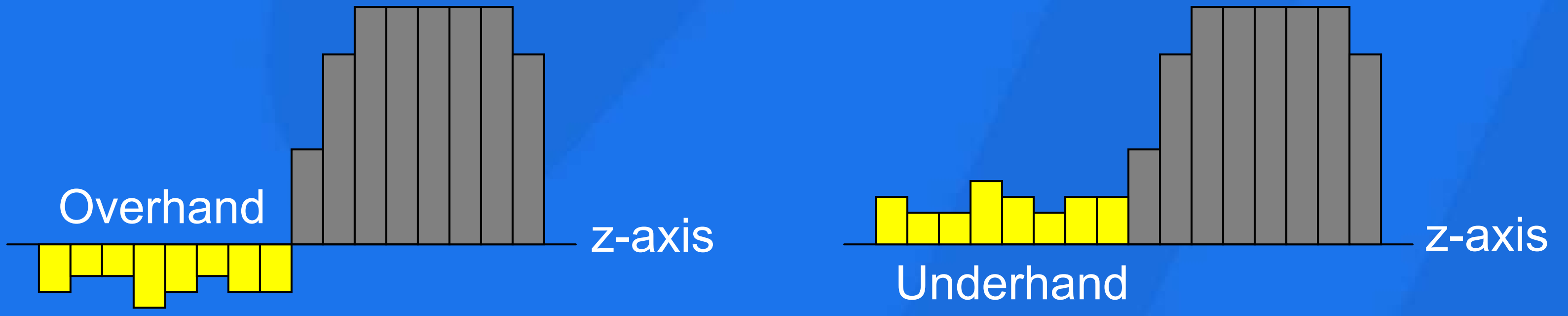
Complex Gesture Recognition:
Topspin, No Spin, or Backspin



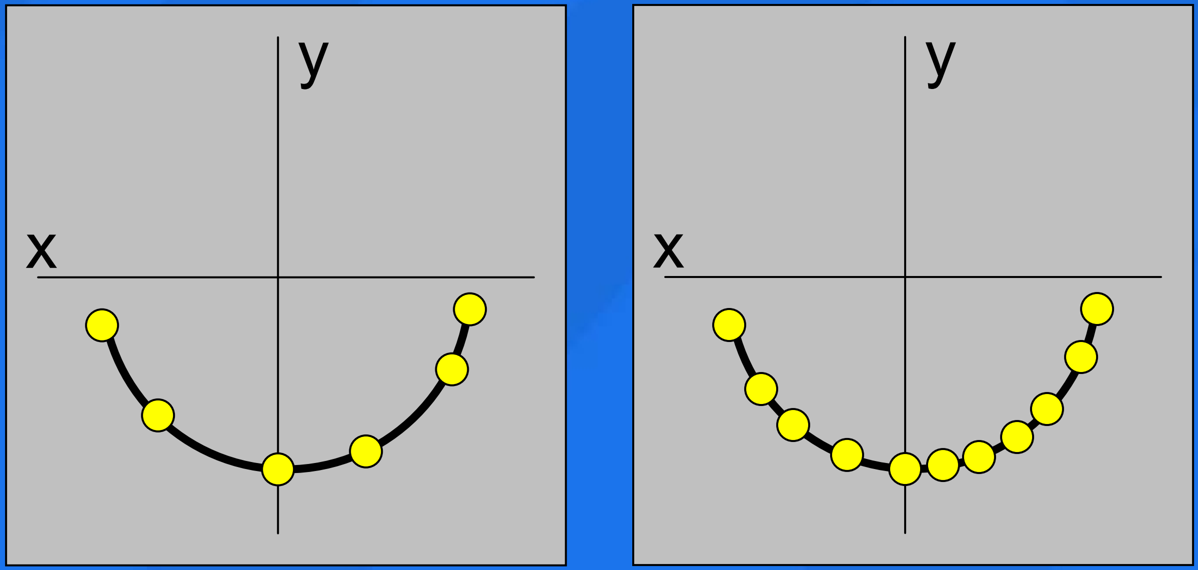
Topspin　　No Spin　　Backspin

Complex Gesture Recognition:
Underhand or Overhand

- Look at z-axis before swing
  - Negative = Overhand
  - Positive = Underhand



Complex Gesture Recognition:
Hard Hit or Soft Hit



Hard Hit   Soft Hit

Nintendo
Wii SUMMIT 2008

Complex Gesture Recognition:
Hard Hit or Soft Hit

Position

↓ Change in Position

Velocity

↓ Change in Velocity

Acceleration

↓ Change in Acceleration?

Complex Gesture Recognition:
Hard Hit or Soft Hit

Position

↓ Change in Position

Velocity

↓ Change in Velocity

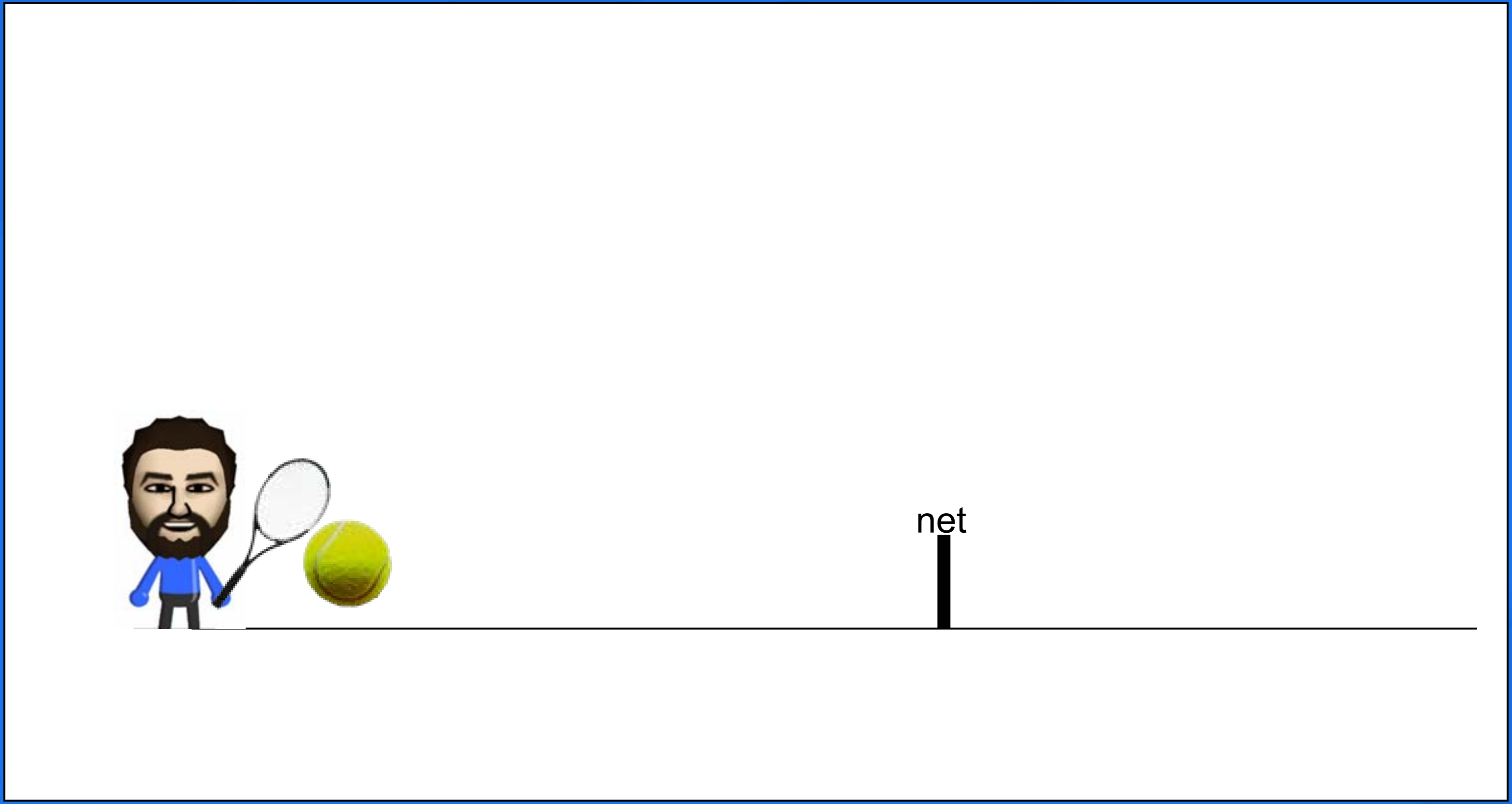
Acceleration

↓ Change in Acceleration

Jerk

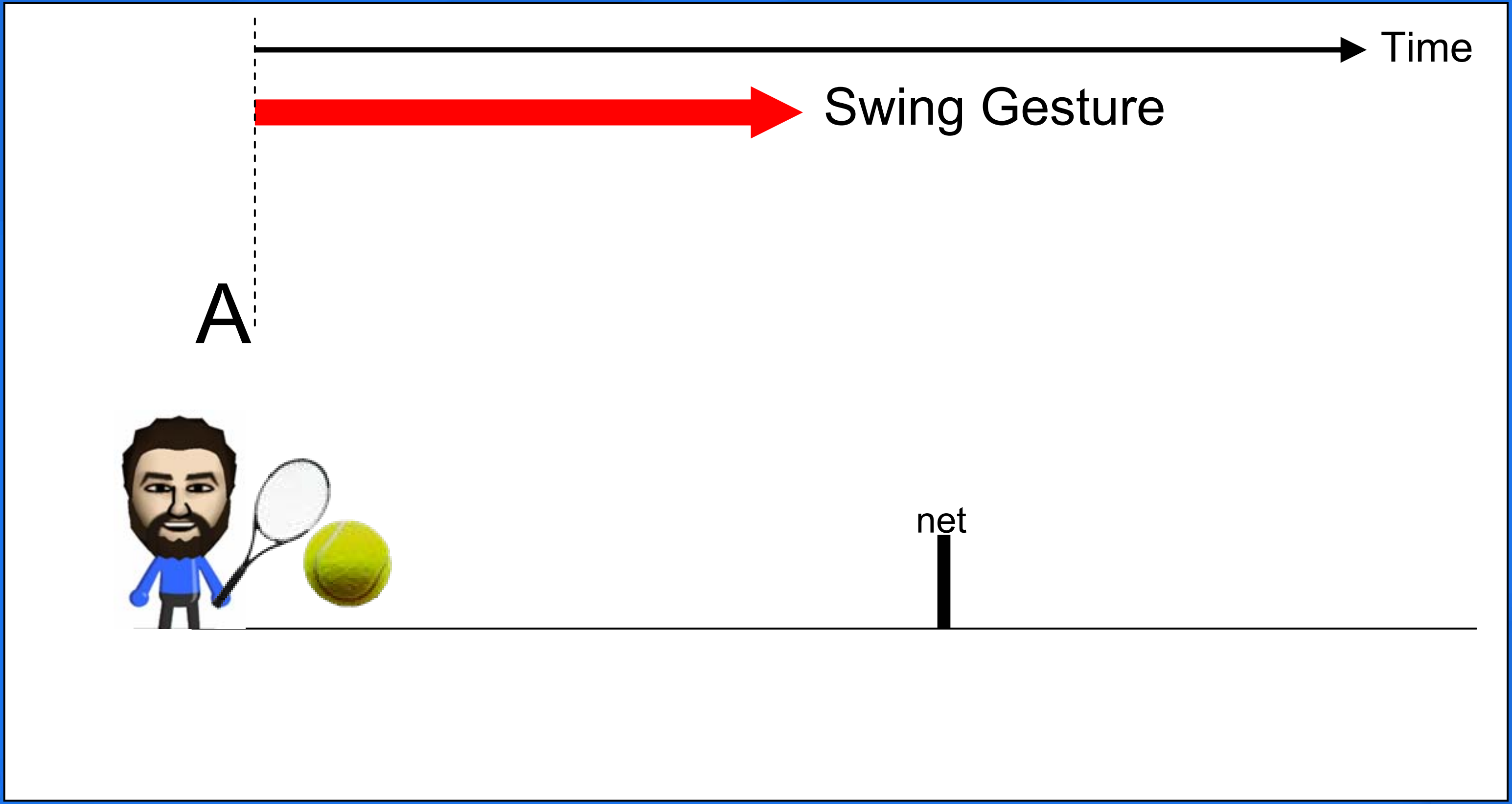
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Sequence of events during a swing and hit



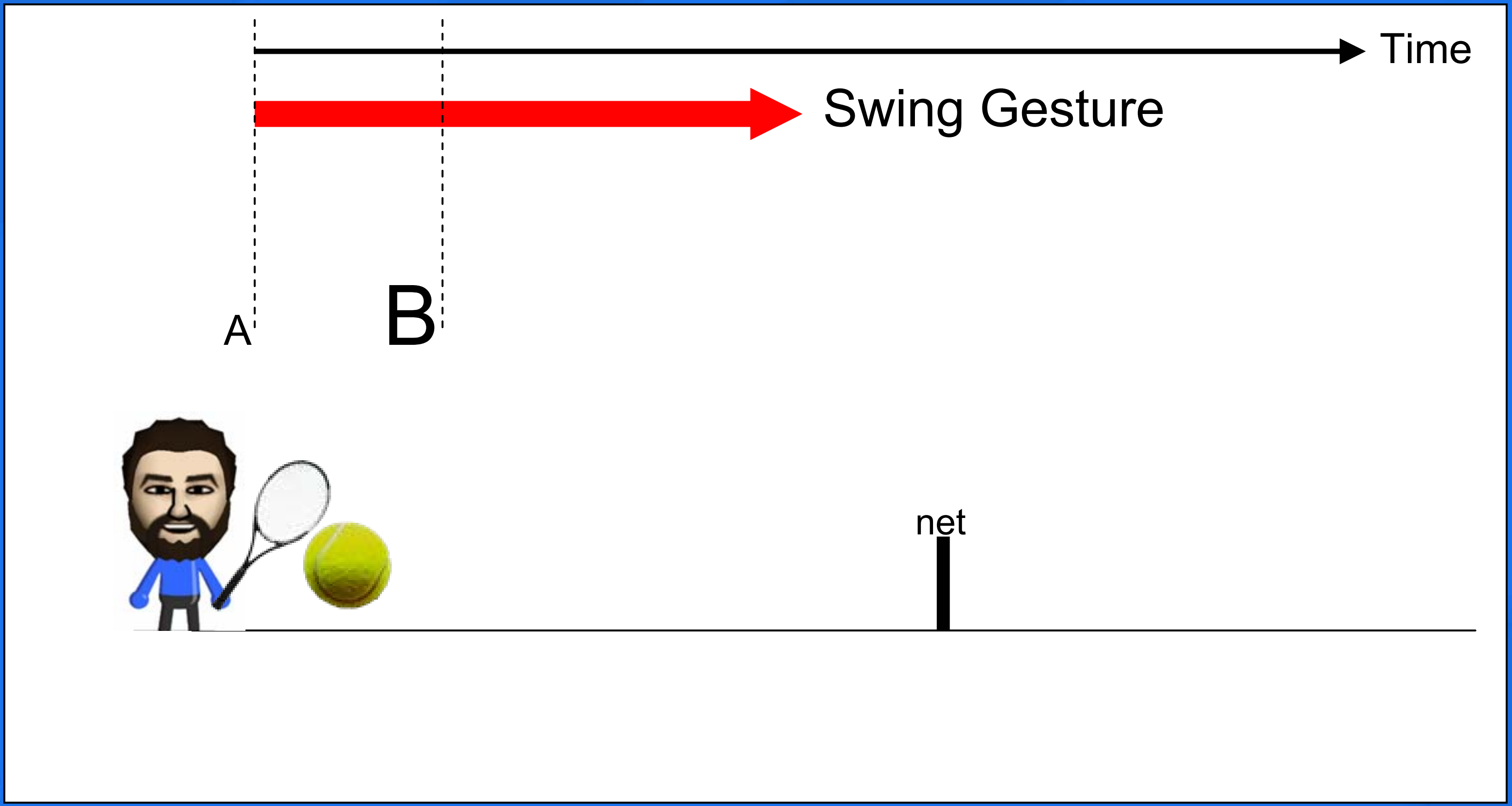
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Time A: Swing started by player



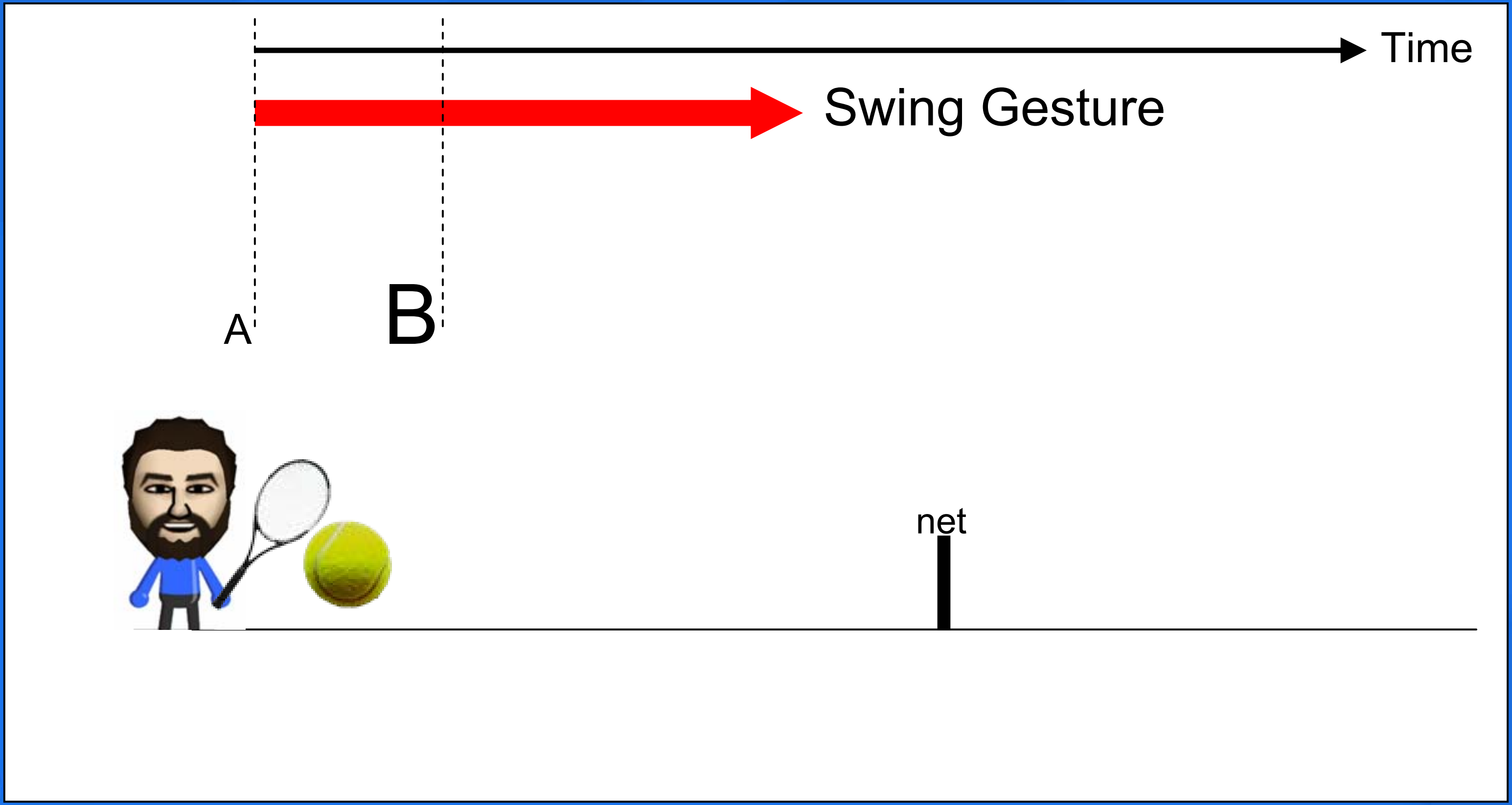
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Time B: Detect left or right swing



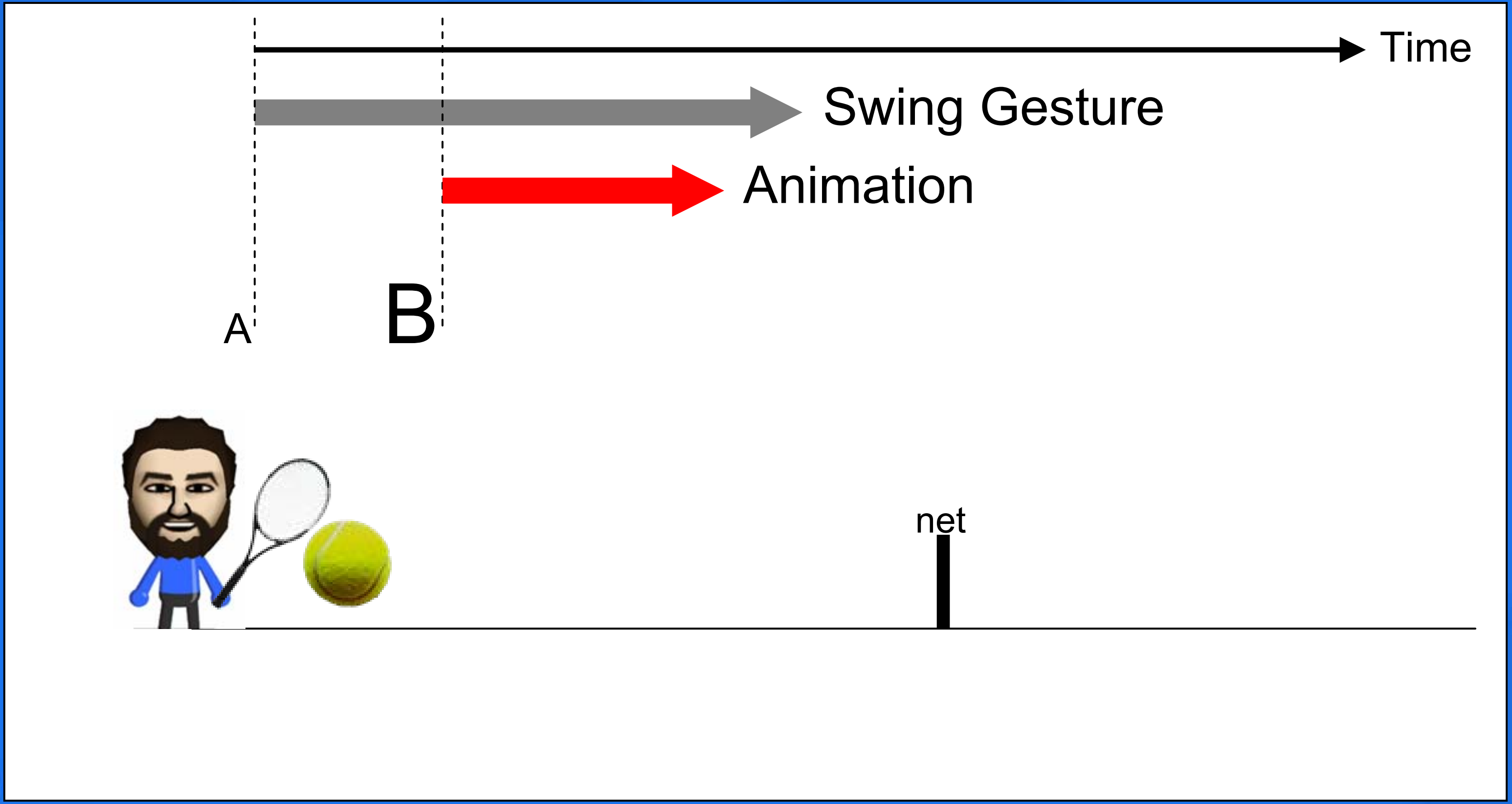
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Time B: Detect underhand or overhand



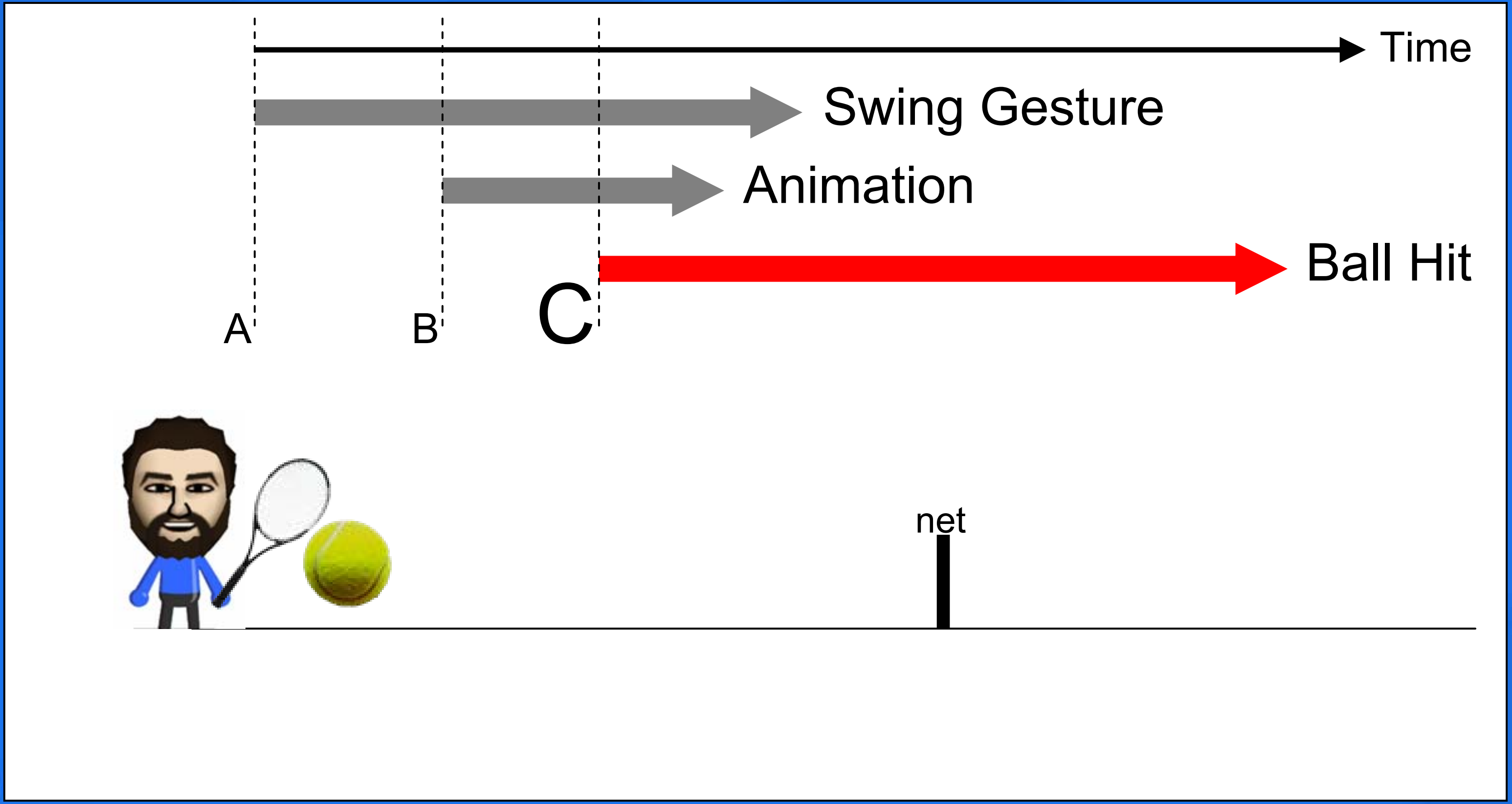
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Time B: Start animation (left/right, over/under)



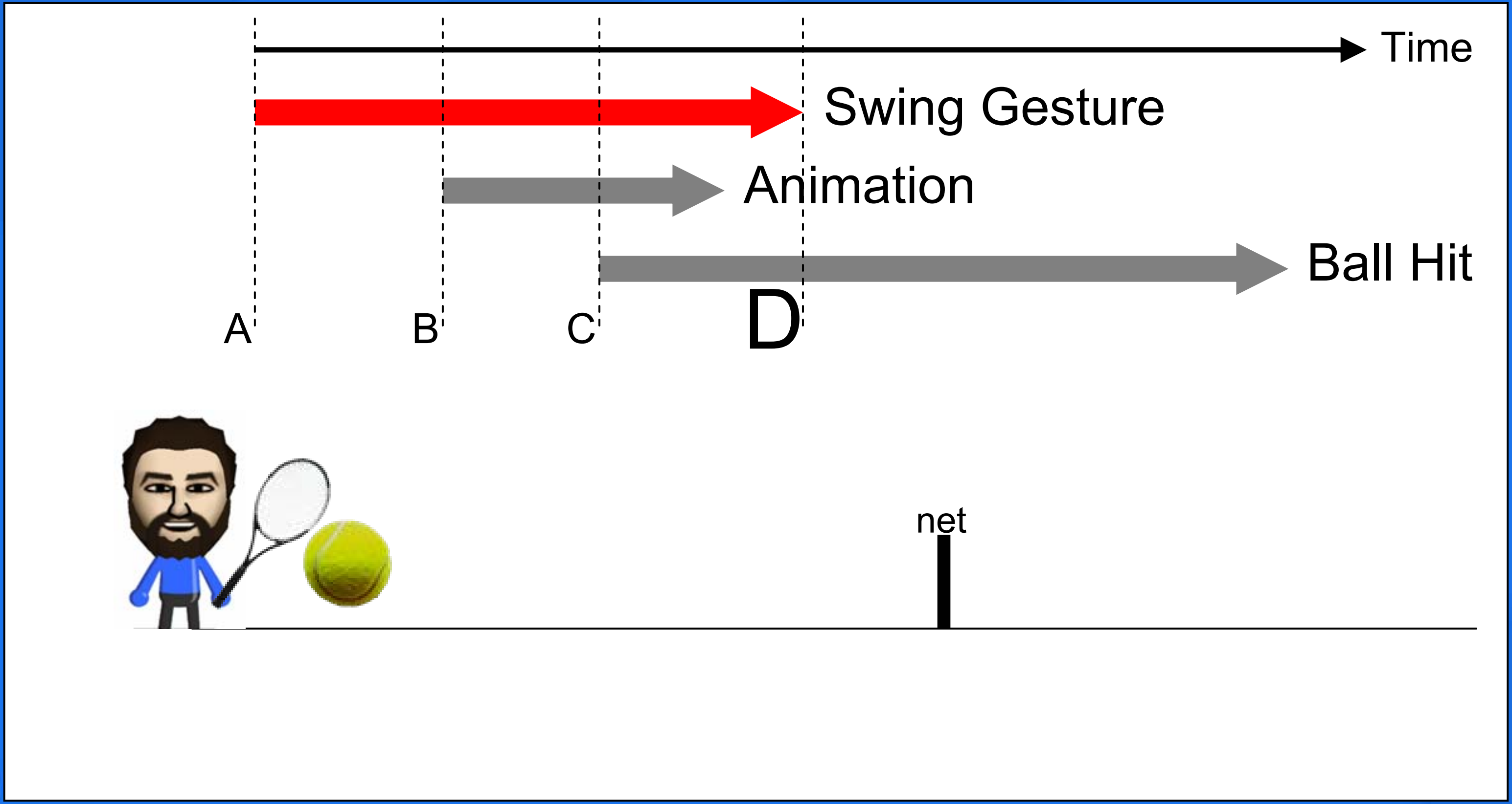
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Time C: Racket collides with ball



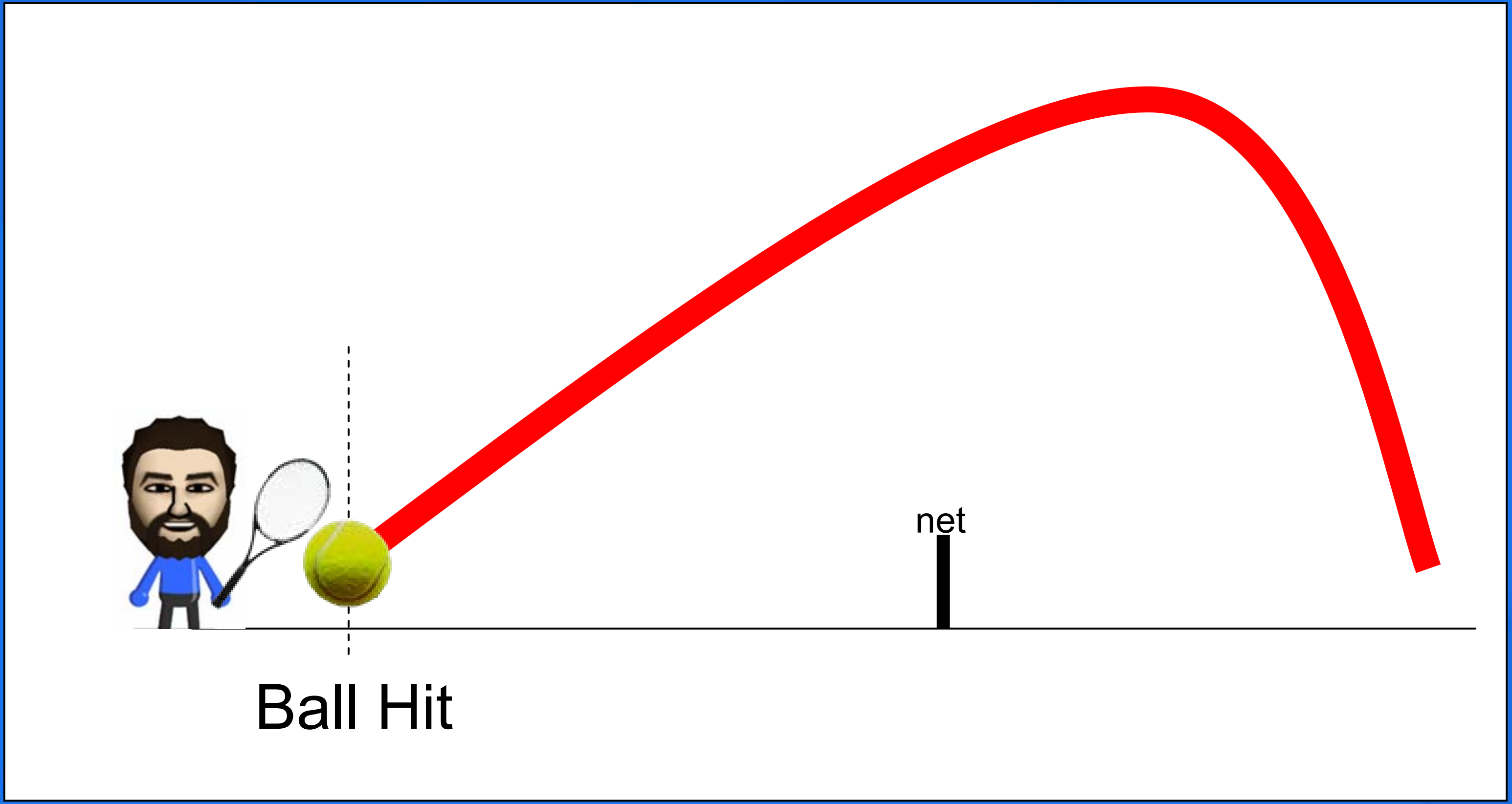
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Time D: Velocity and spin recognized



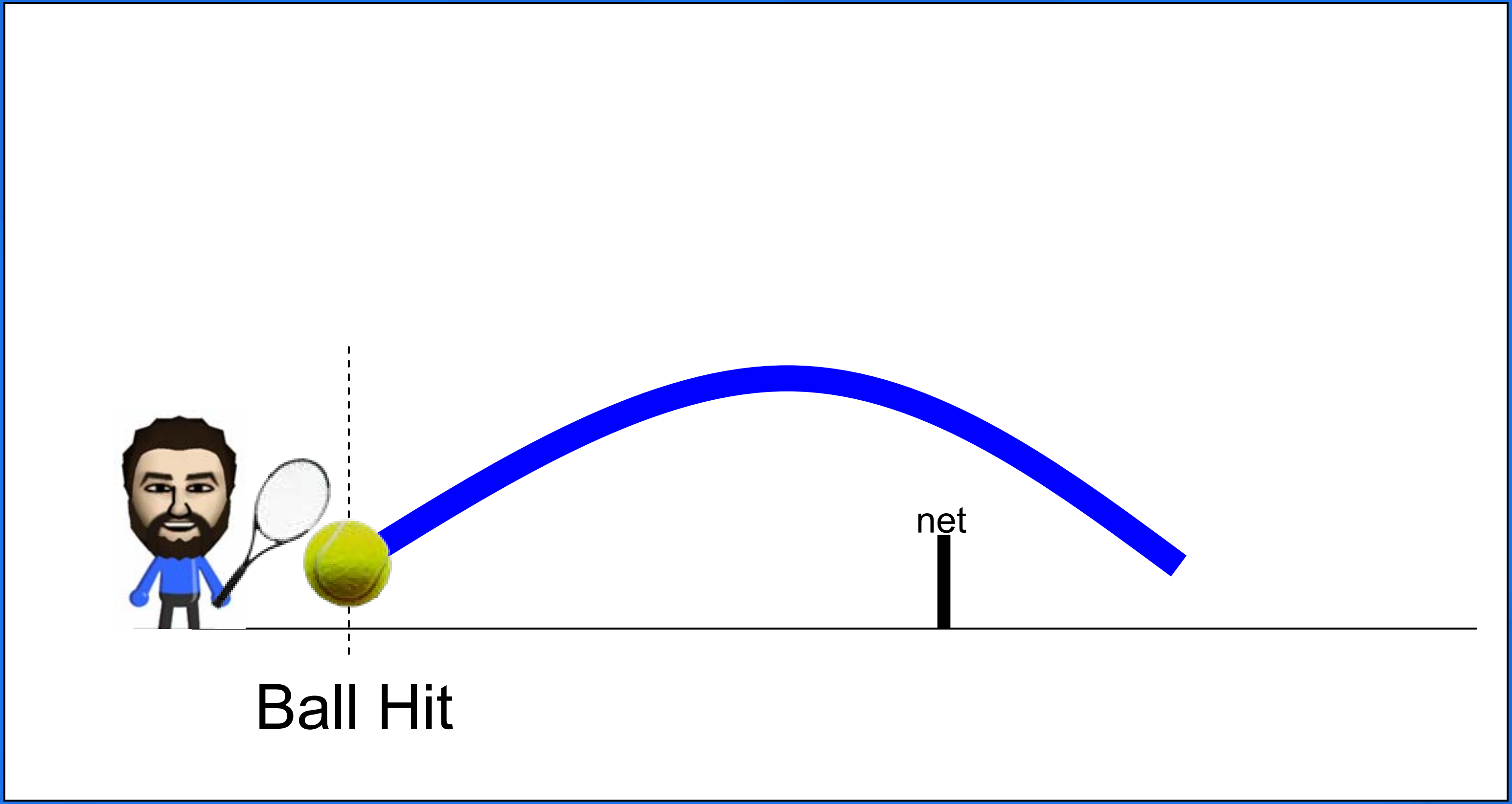
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- High velocity and backspin



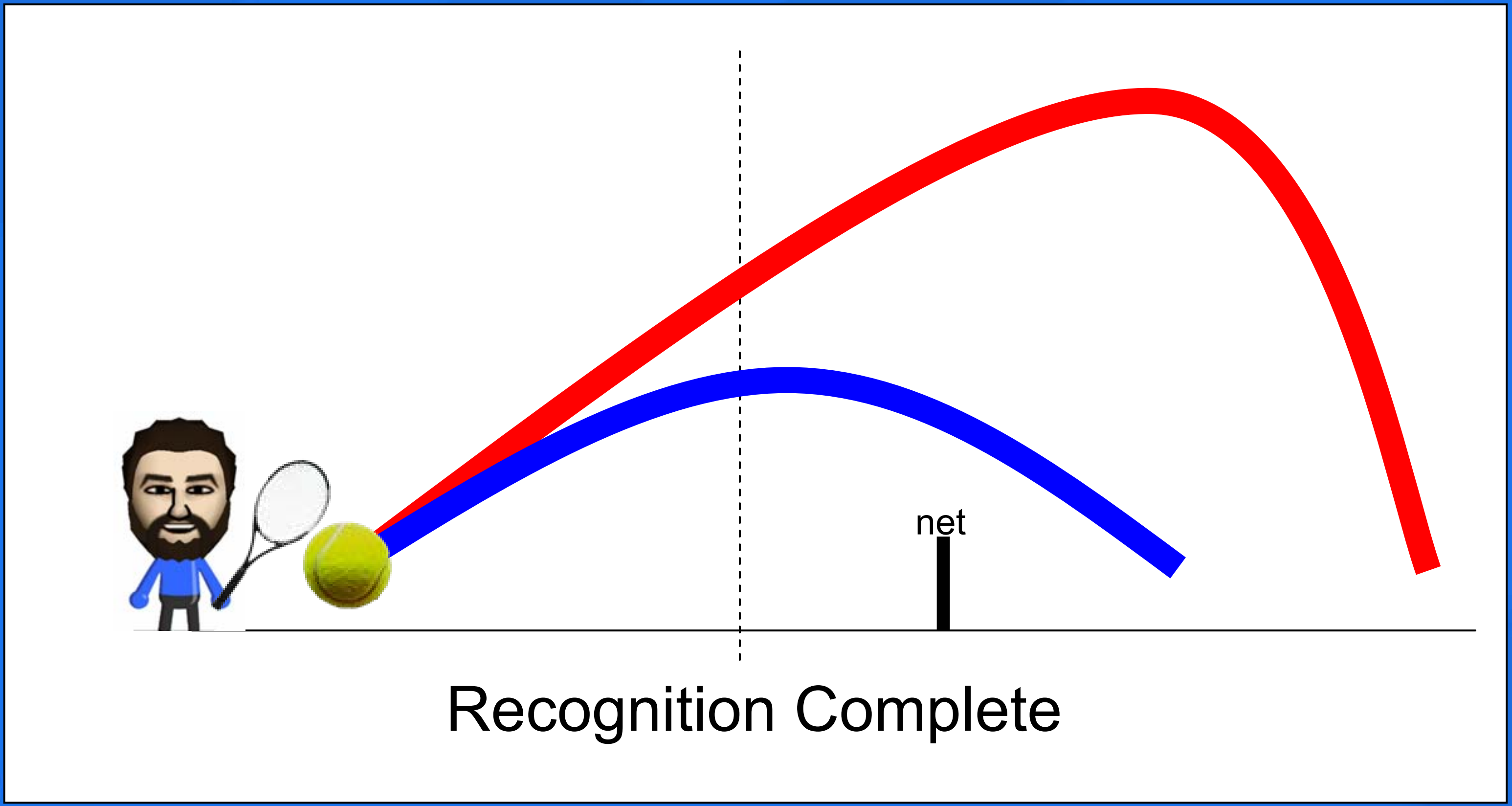
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Average speed with no spin



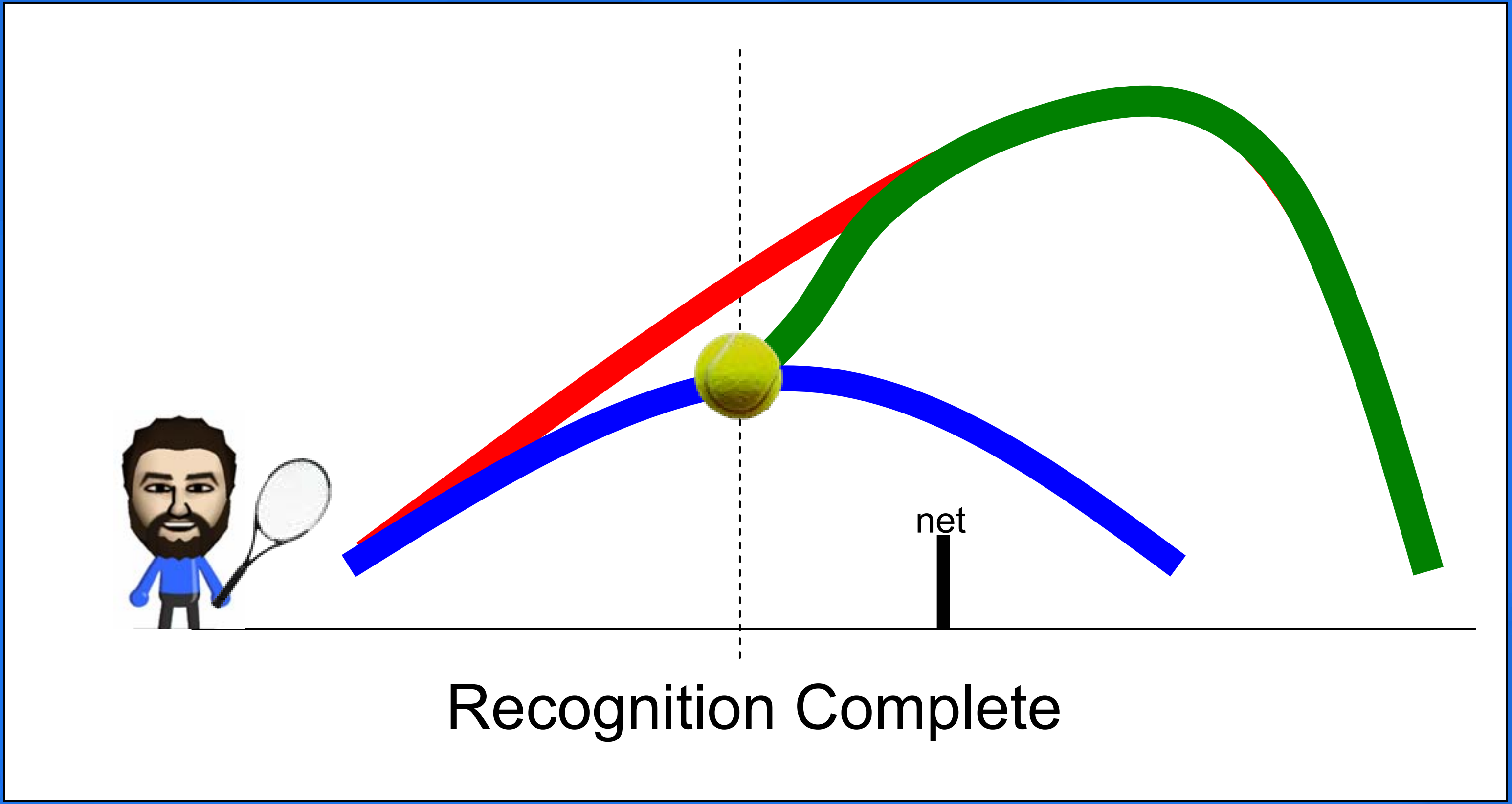
Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Velocity and spin are detected late

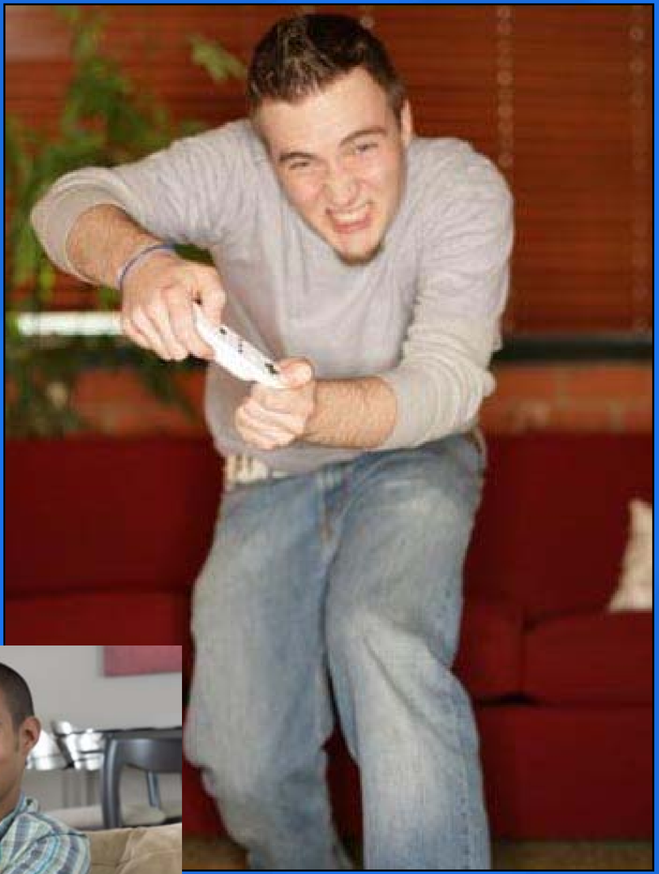


Complex Gesture Recognition:
Wii Sports Tennis Timeline

- Interpolate ball to desired trajectory



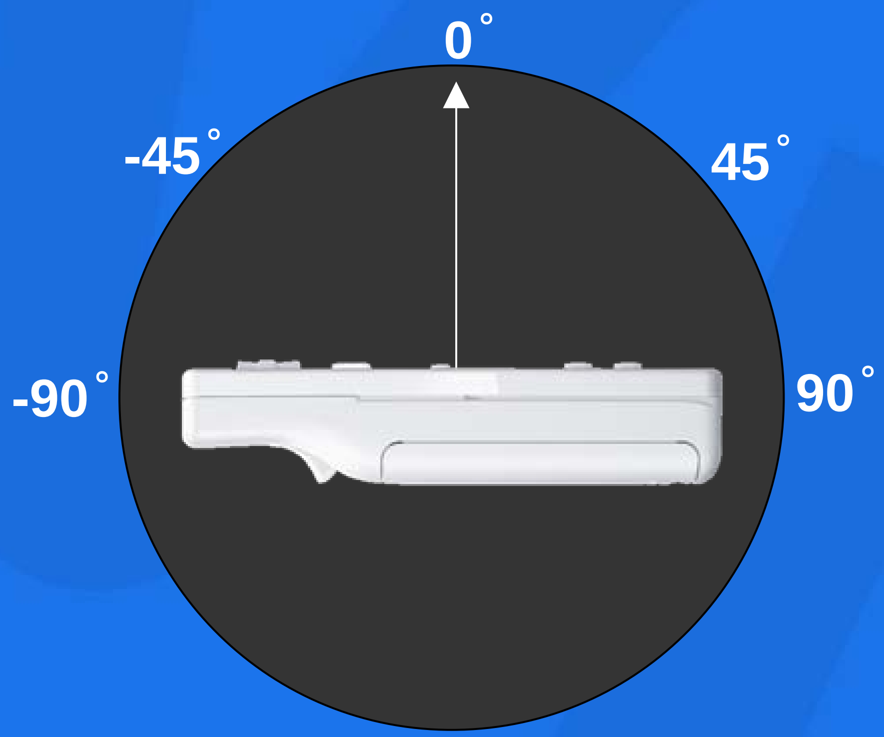
Accelerometer Applications: Steering



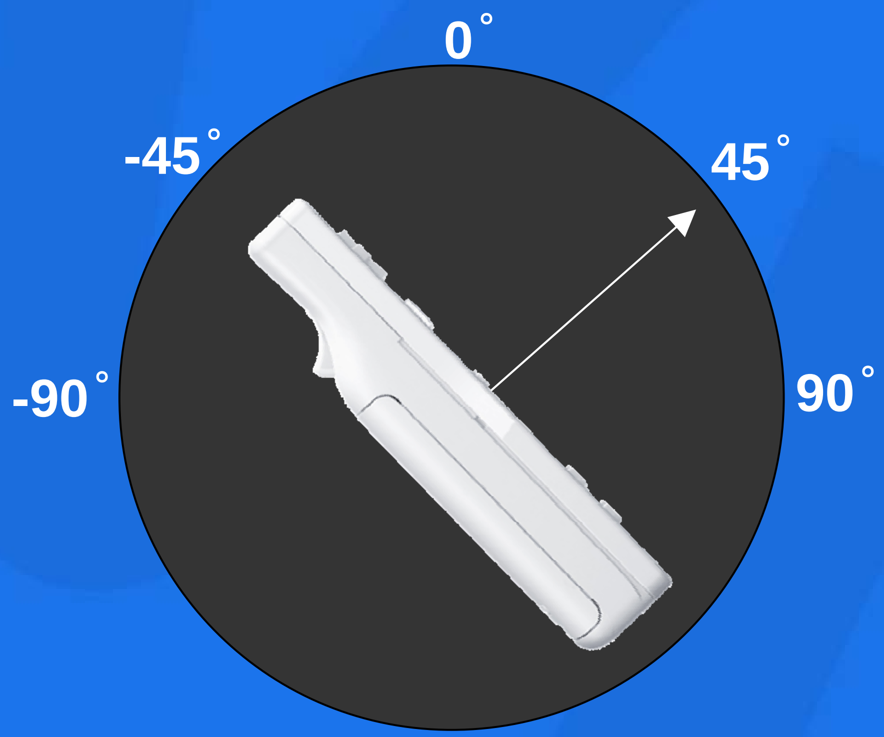
Steering and Rotating

- Robust and reliable
- Various orientations
  - Sideways / Wii Wheel
  - Paper airplane
  - Flight stick

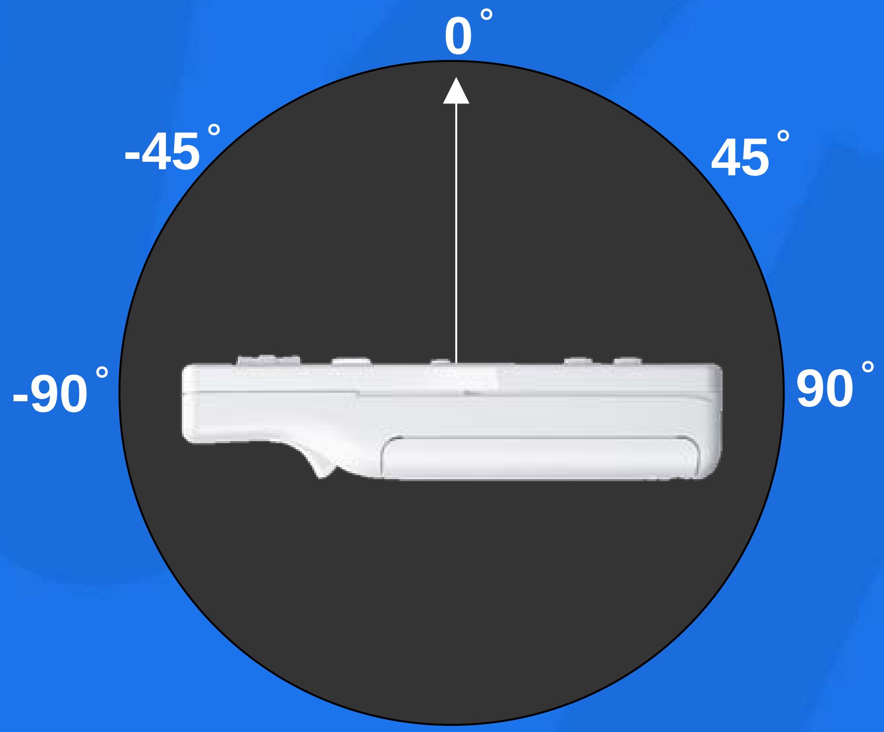
Steering and Rotating: Desired Angles



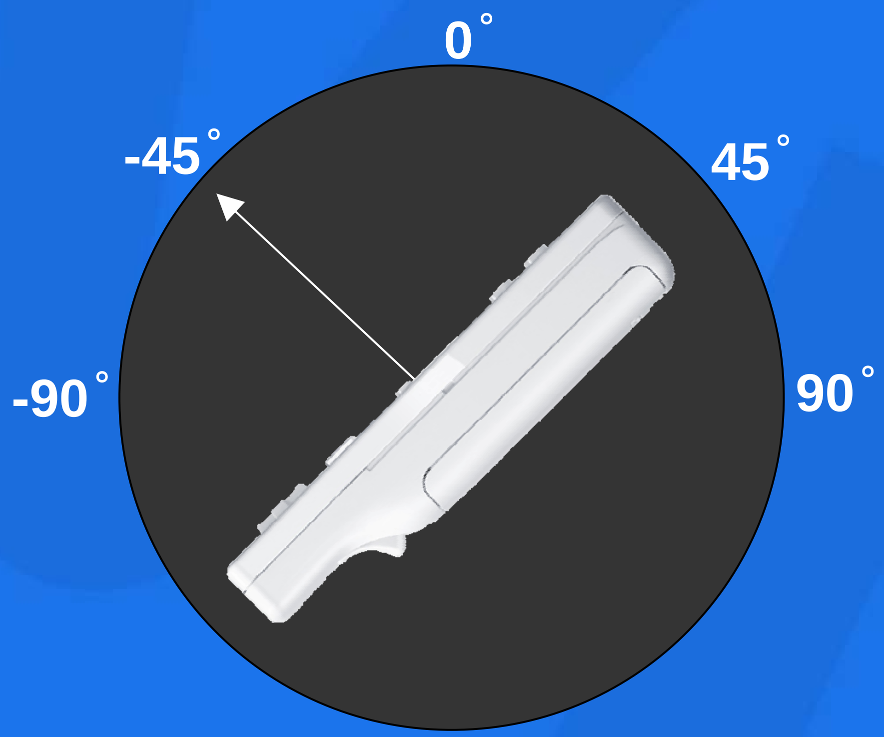
Steering and Rotating: Desired Angles



Steering and Rotating: Desired Angles

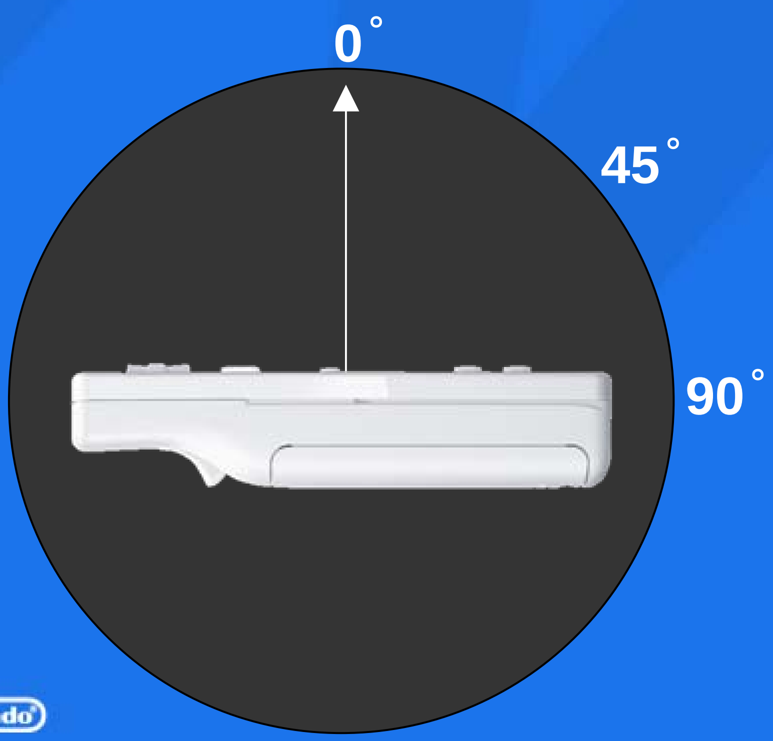


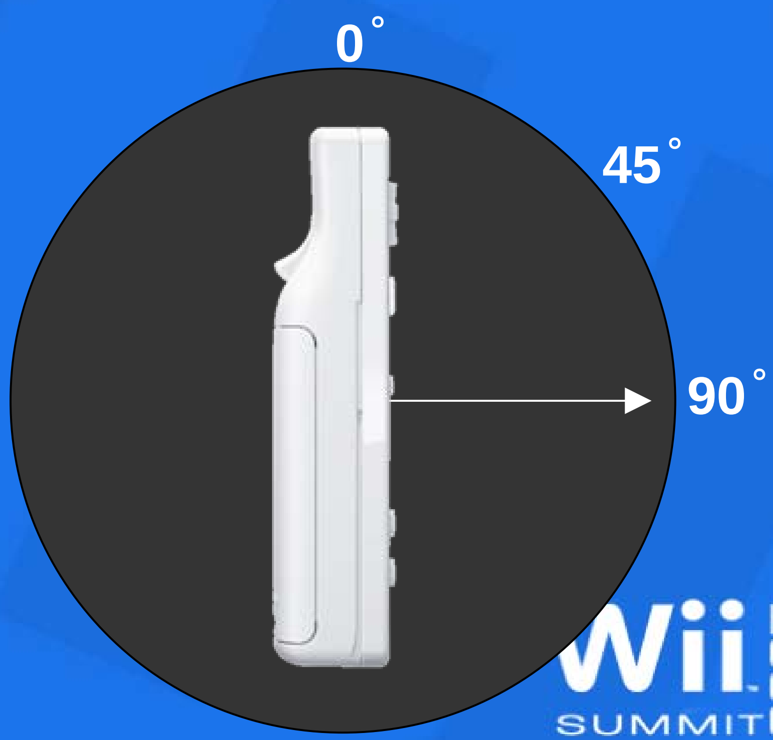
Steering and Rotating: Desired Angles



Steering and Rotating: Angle Conversion

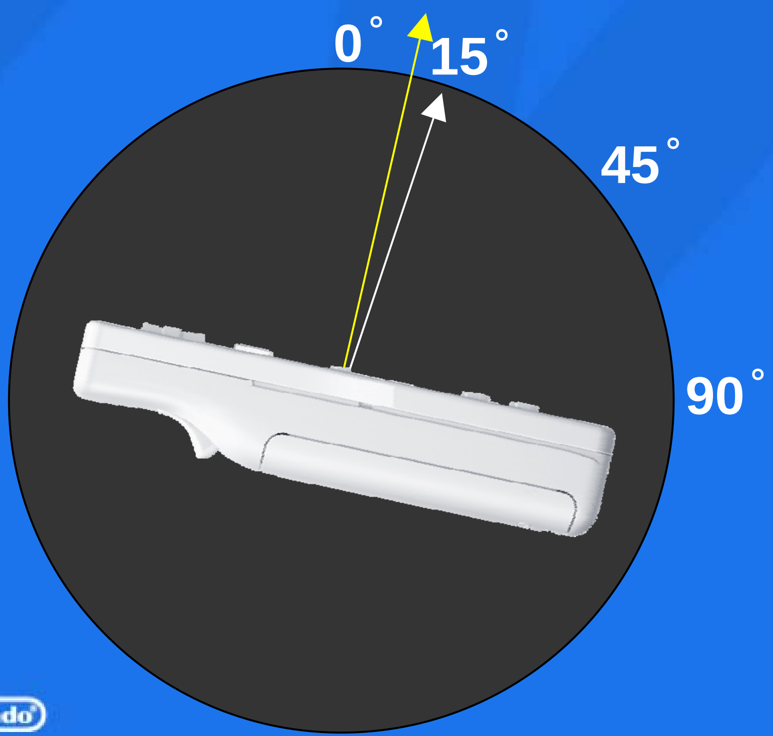
- Wrong way
  - Multiply z-axis by 90 degrees

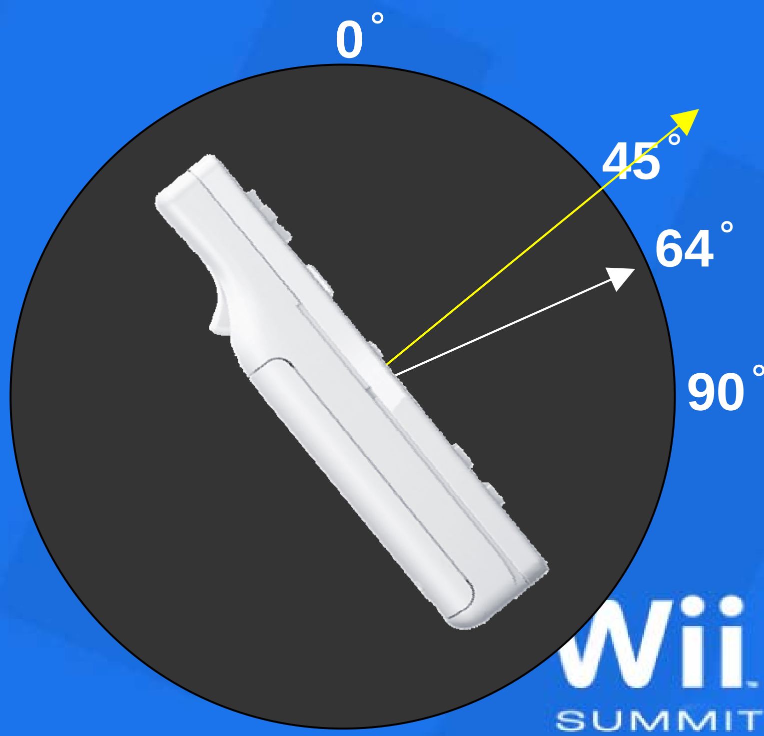




Steering and Rotating: Angle Conversion

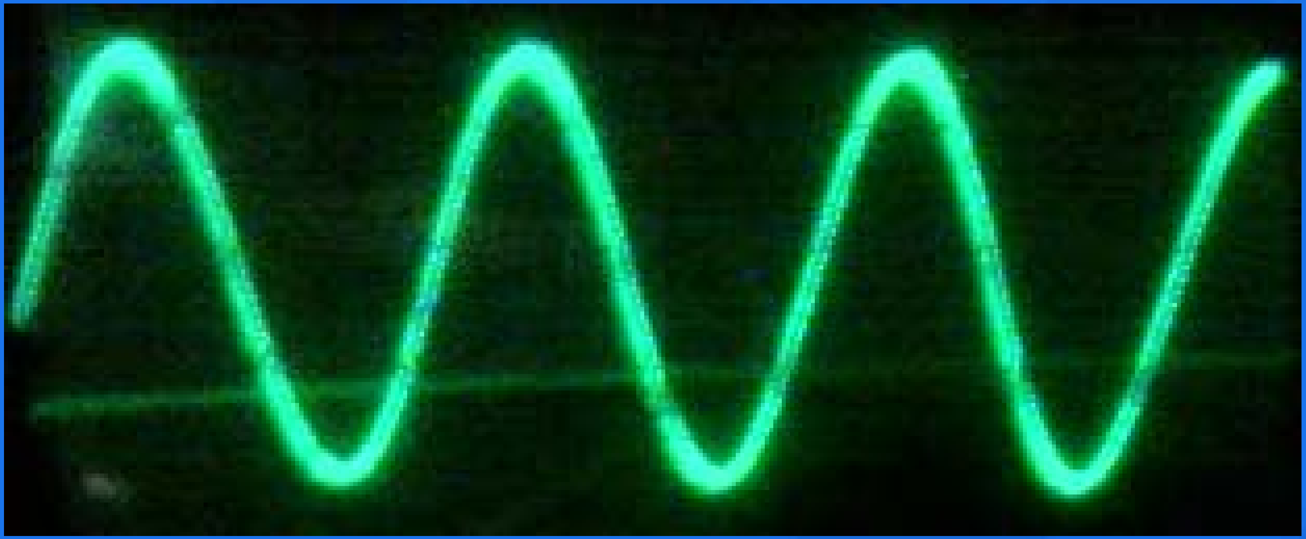
- Wrong way (multiply z-axis by 90 degrees)
  - Close, but causes "swerving" near zero degrees





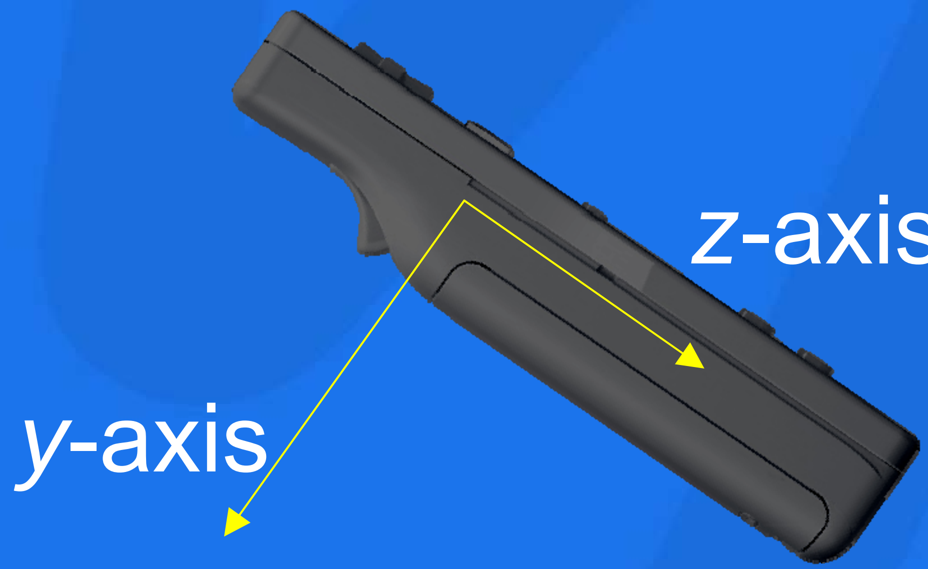
Steering and Rotating: Angle Conversion

- Correct Way
  - Use trigonometry (sin or cos)

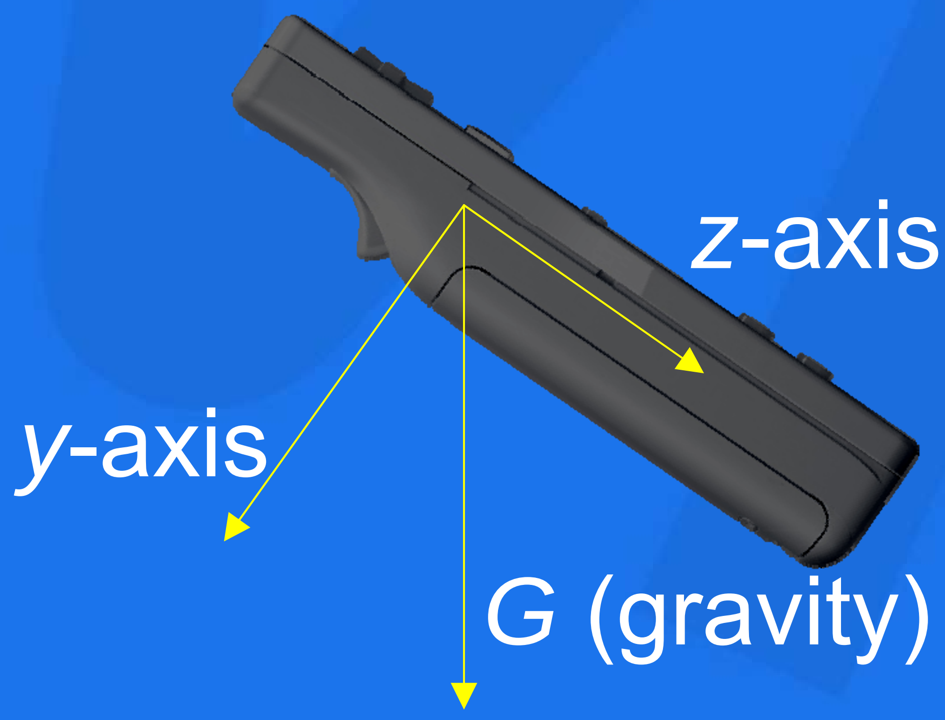


Steering and Rotating: Trigonometry Visualization

Steering and Rotating: Trigonometry Visualization

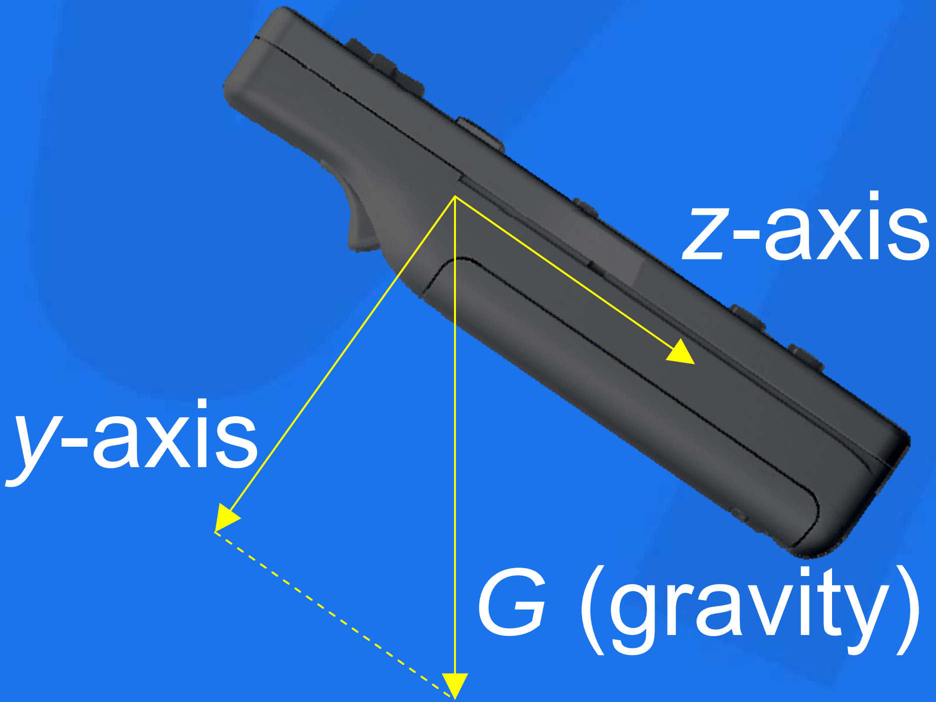


Steering and Rotating: Trigonometry Visualization



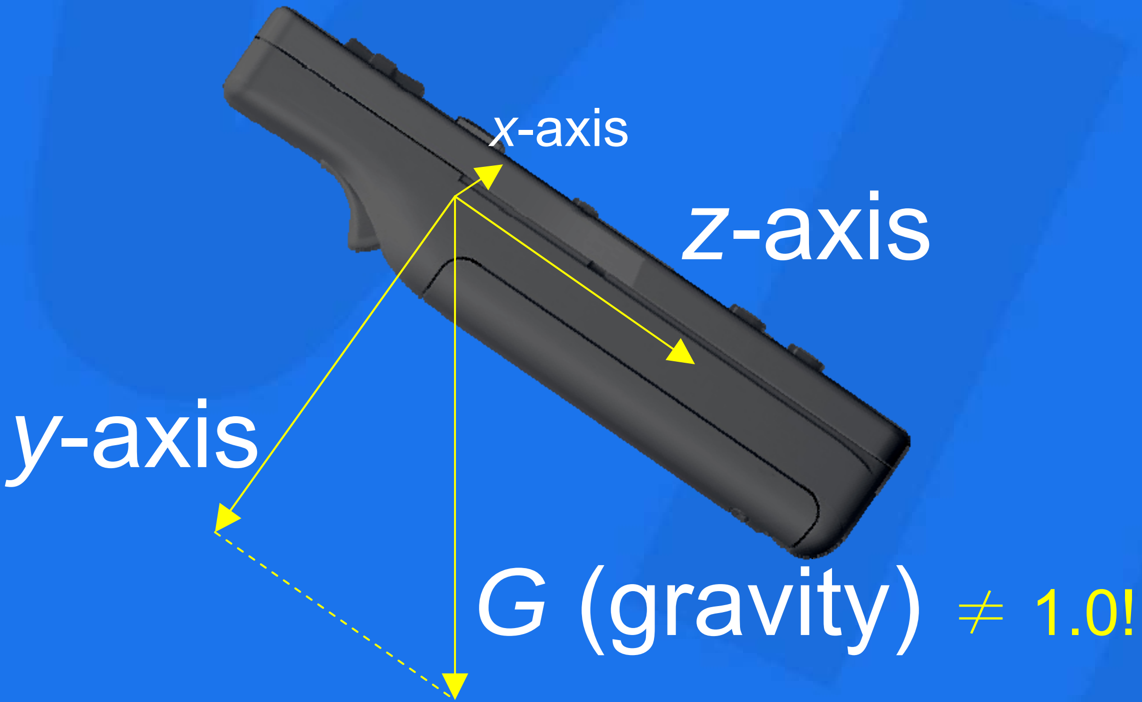
Steering and Rotating: Trigonometry Visualization

$$G = \sqrt{yAxisAcceleration^2 + zAxisAcceleration^2}$$

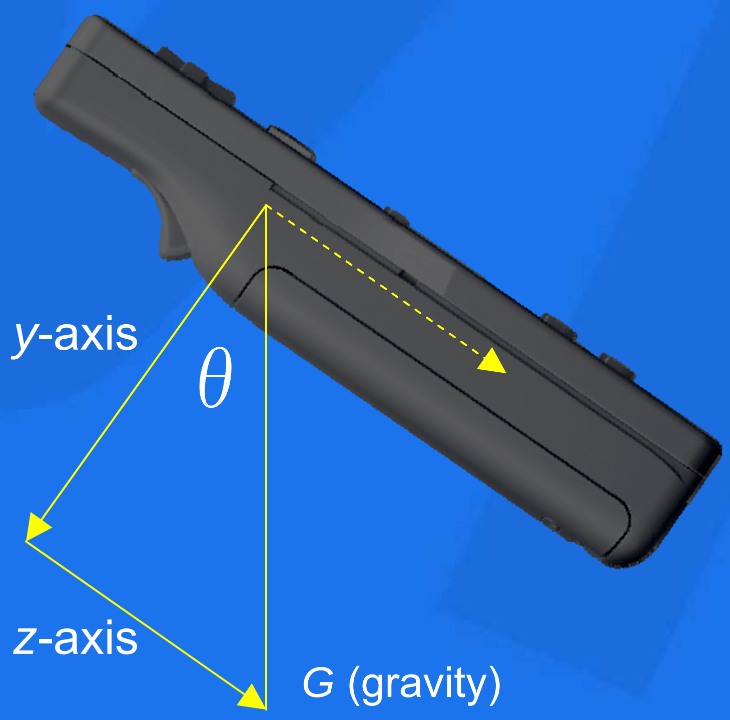


Steering and Rotating: Trigonometry Visualization

$$G = \sqrt{yAxisAcceleration^2 + zAxisAcceleration^2}$$

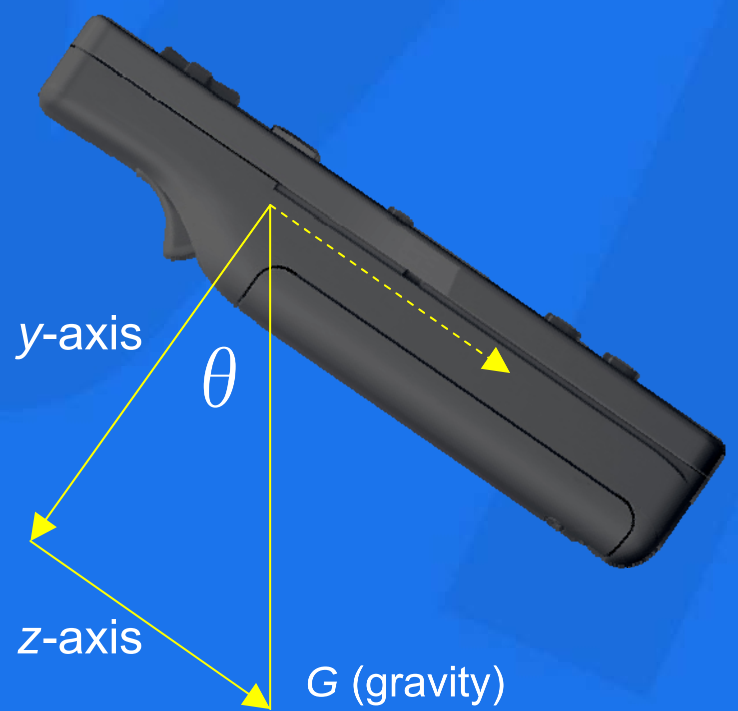


Steering and Rotating: Trigonometry Visualization



Steering and Rotating: Trigonometry Visualization

$$\sin(\theta) = \frac{opposite}{hypotenuse} = \frac{zAxisAcceleration}{\sqrt{yAxisAcceleration^2 + zAxisAcceleration^2}}$$

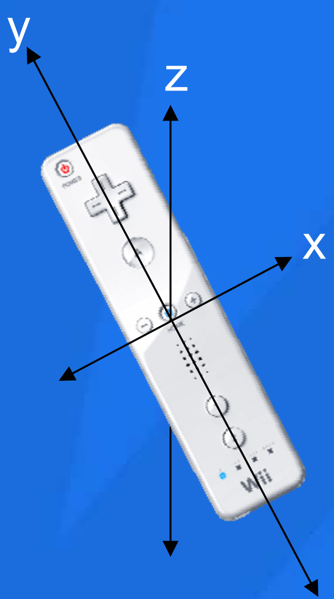


Steering and Rotating: Trigonometry Visualization

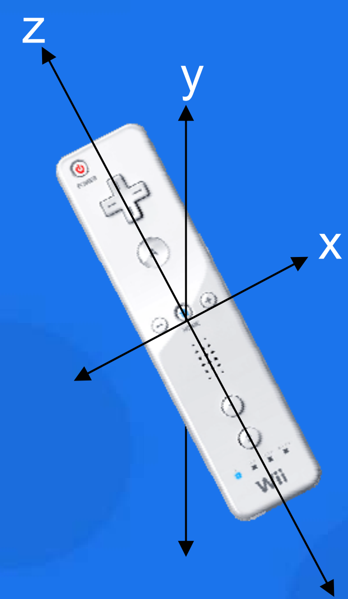
$$\theta = \arcsin\left(\frac{zAxisAcceleration}{\sqrt{yAxisAcceleration^2 + zAxisAcceleration^2}}\right)$$

Avoiding Jitter in Steering

- Player's hands are shaky
  - Smooth out accelerometer data
  - KPADSetAccParam(chan, play, sensitivity);
    - <play> should be between 0 and 0.05
    - Note that these are smoothed independently for each axis



WPAD vs KPAD



- WPAD
  - Low level
  - y-axis is forwards
  - No smoothing
- KPAD
  - High level
  - z-axis is forwards
  - Offers smoothing

Pointing Summary

- Perfect for aiming or selecting
- Capable of
  - 2D position
  - Distance
  - Twisting
- Use KPAD library to smooth
  - 2D position
  - Horizontal (twisting)
  - Distance

Accelerometer Summary: Gesture Recognition

- Simple vs Complex
  - Complex takes more development effort and tuning
  - Complex harder to achieve 100% accuracy
  - Try to discern between two options – use your brain!
- Adapt game design to make gesture recognition robust
- Make use of velocity

Accelerometer Summary: Steering

- Remember to use trigonometry
  - Swerving could mean it was implemented wrong
- Use KPAD to smooth values

Wii Balance Board

Wii Balance Board

- Four "balance sensors"
  - Top left, Top right, Bottom left, Bottom right
  - Measures amount of change in pressure
  - Must be set to "zero point", like a typical scale

- Simple function WBCRead() returns total weight measurement from combined sensors
  - Use WBCGetTGCWeight() to correct for temperature and gravitational acceleration

Wii Balance Board

- Download the Wii Balance Board package from WarioWorld.com
- Won't be sold separately
  - Sold only with Wii Fit
  - Your game must work with or without the Wii Balance Board

Questions?

Ask me during the reception/breaks

Or e-mail support@noa.com