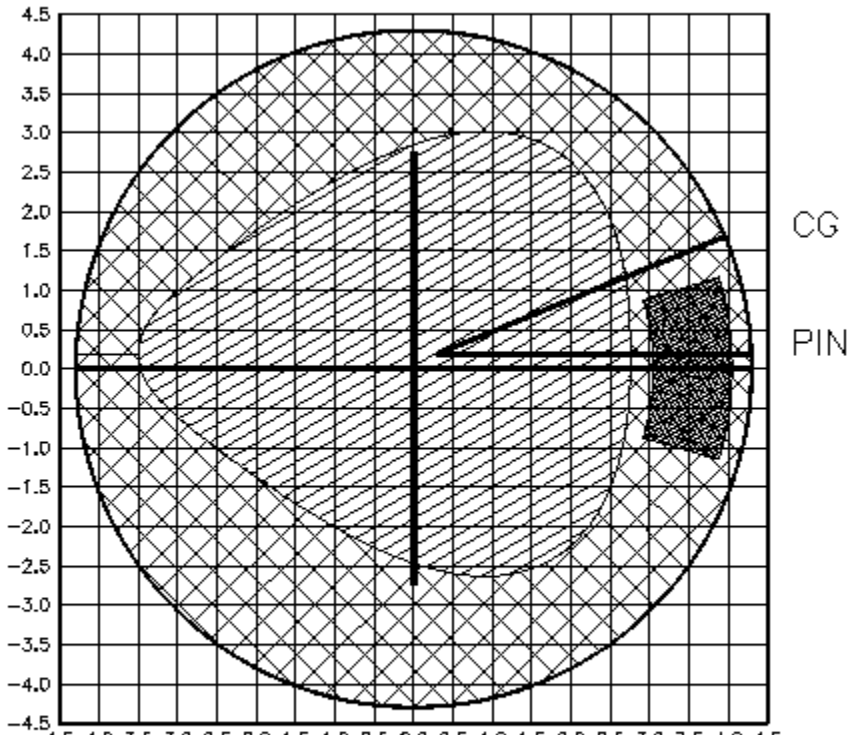
Physics of Bowling Balls



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Overview

- Summary of game's objectives
- Important aspects of the game, in order:
  - correct fundamentals (lessons)
  - mental approach (psychology)
  - body control (DNA)
  - equipment (cool *high-tech* examples)
- Equivalence to golf, horseshoes

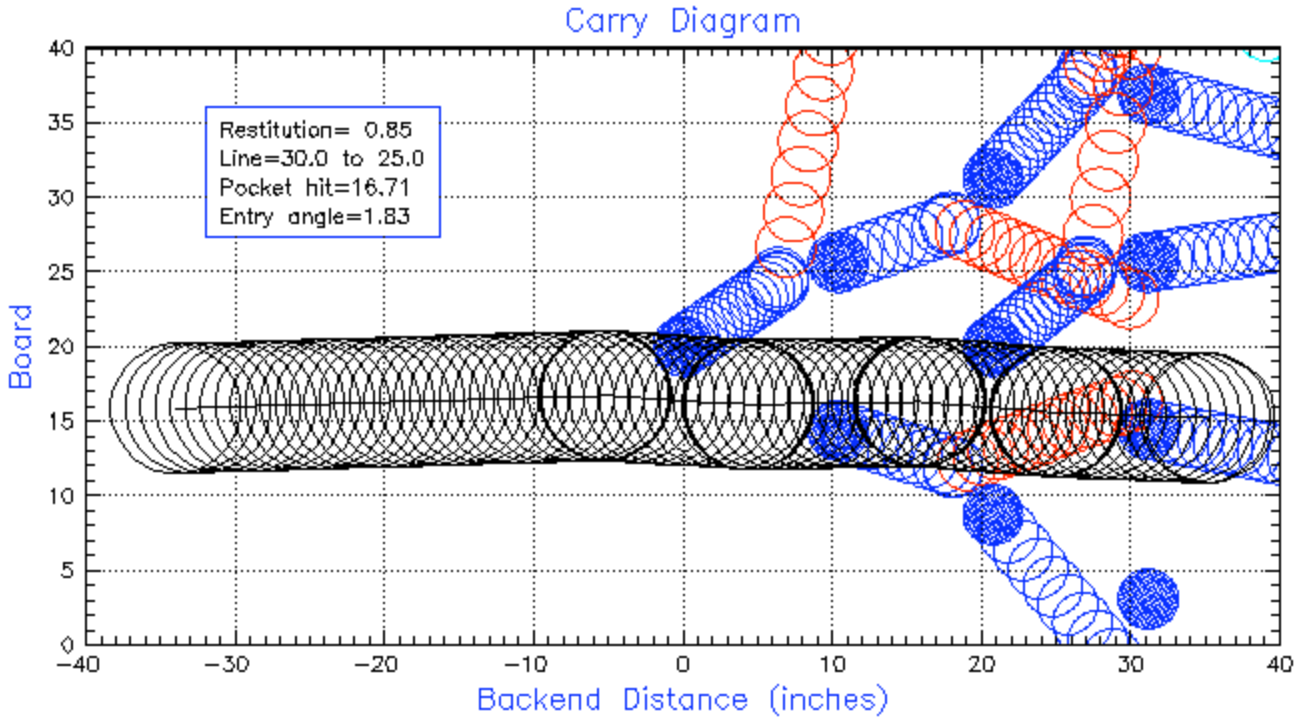
Objectives

- Maximize *score* by getting all 10 pins
  - every shot … repetition
  - correct impact placement of hit
  - correct entry angle to pins, well-matched with the rotational parameters of delivery
  - ball trajectory well-matched with surface, friction, oil pattern and migration thereof
- If you don't *strike*, convert every *spare*

Hit Placement & Angle

- Straight line from gutter to headpin
  - only 1.5 degree entry angle
  - most hits centered on headpin leave pins on both sides (*split*)
  - want to hit 1-3 pocket (right handers, 86%) or 1-2 pocket (left handers, 14%)
- Entry angle in 4-6^{o} range is desirable

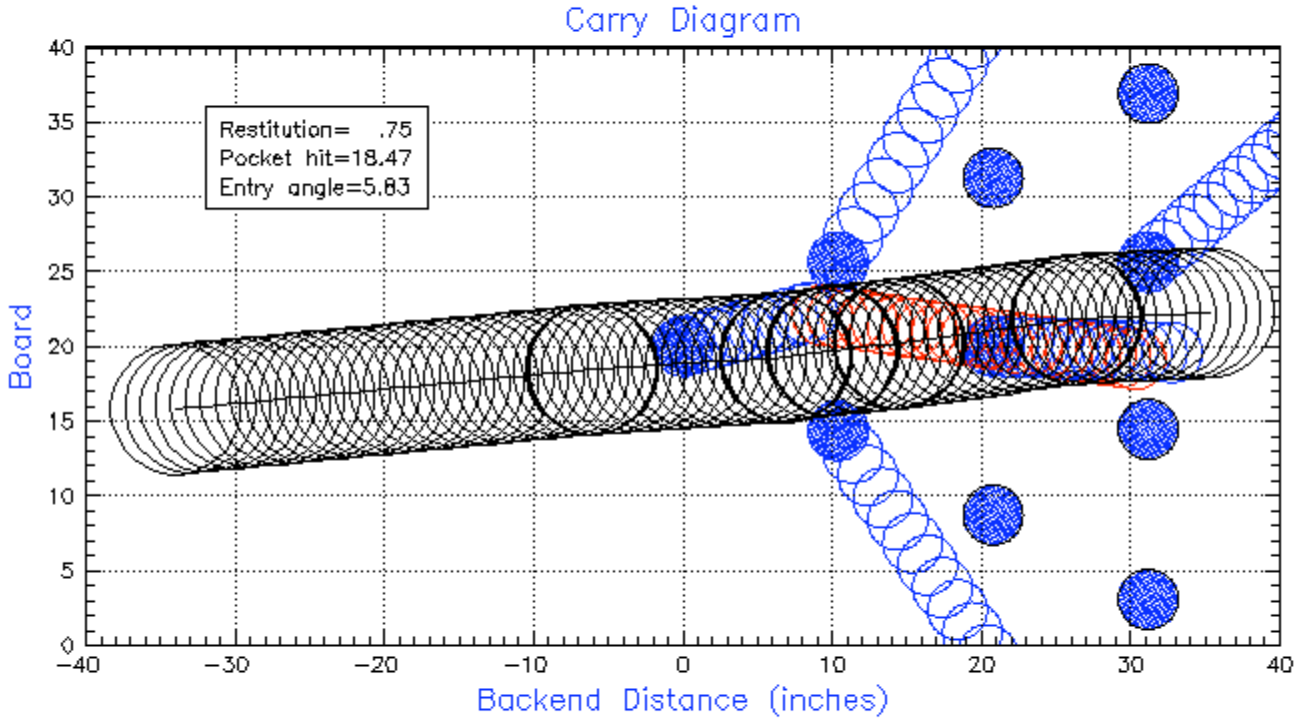
Small entry angle



10-pin leave

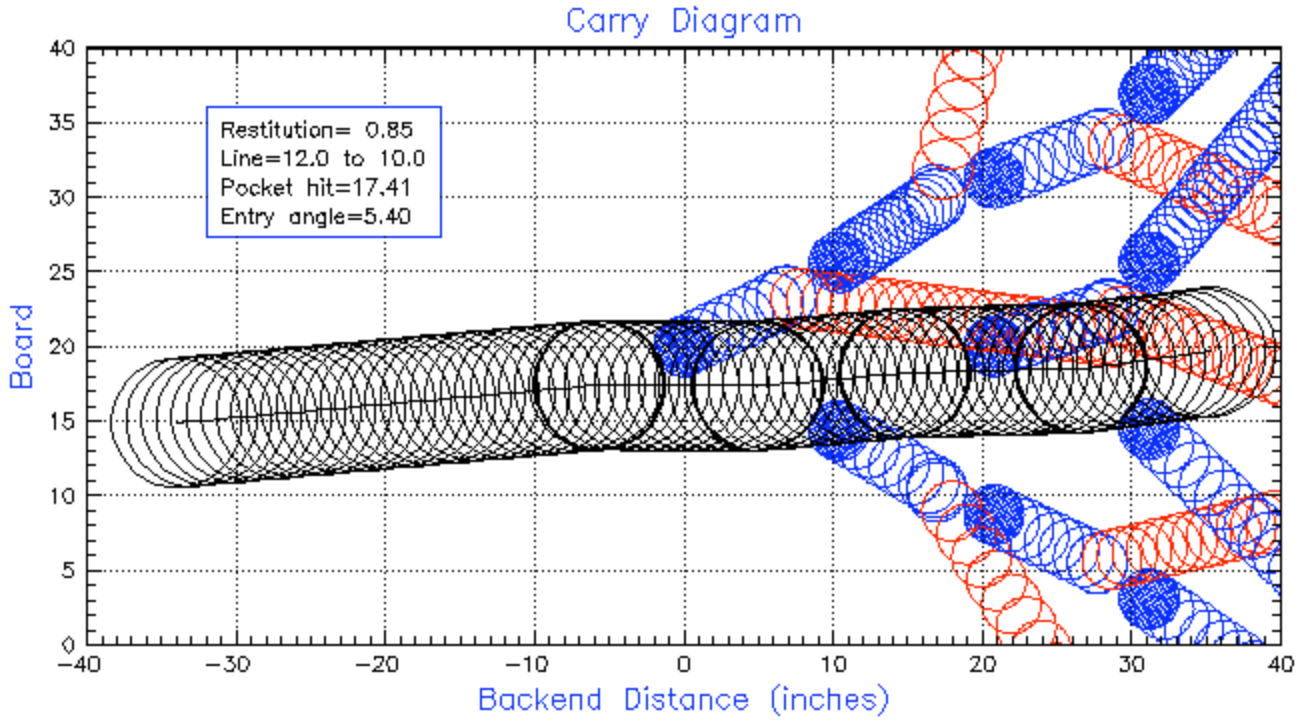
PBA tree blend, 9 units to 5 outside; Purple Hammer (shiny) label shift loaded

Big entry angle



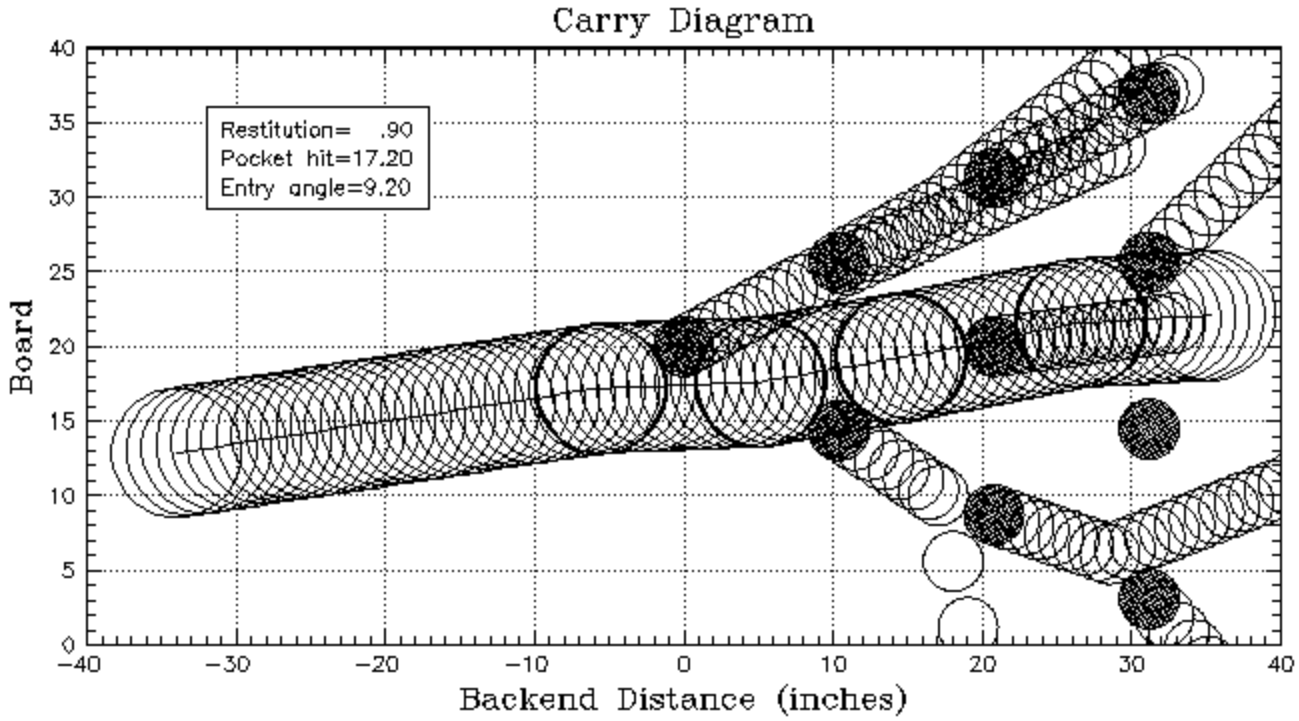
Too much headpin,
this is a bad result

Perfect Hit



PBA tree blend, 9 units to 5 outside; Purple Hammer (shiny) label shift loaded

Near-Perfect Hit

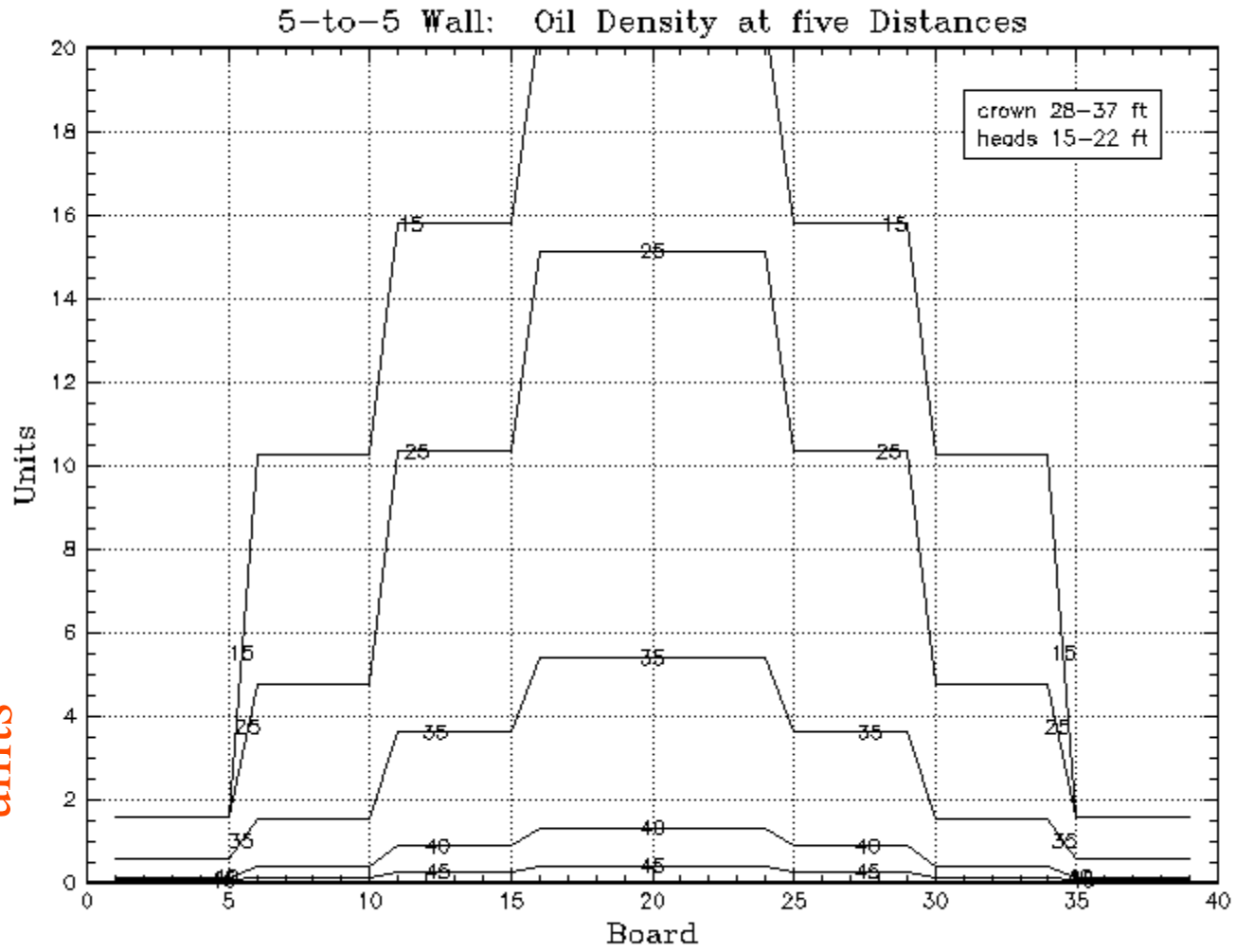


"Solid" 9 pin

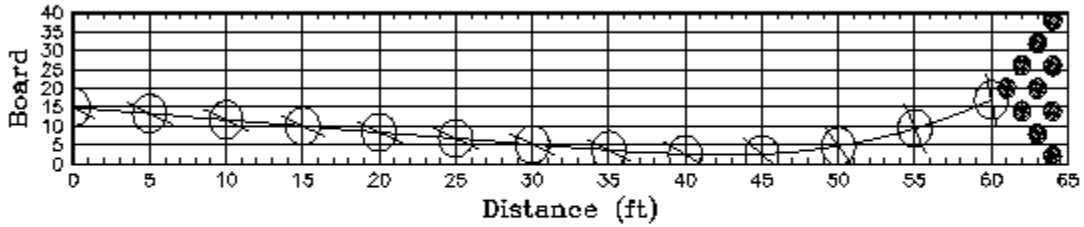
Solid 9 -- Swing 15 to 10; Breakpoint 2; 18 mph; 20 revs; 9 degree entry

Oil Pattern on Lane Surface

Threshold of friction: 3-10 units



Ball Trajectory

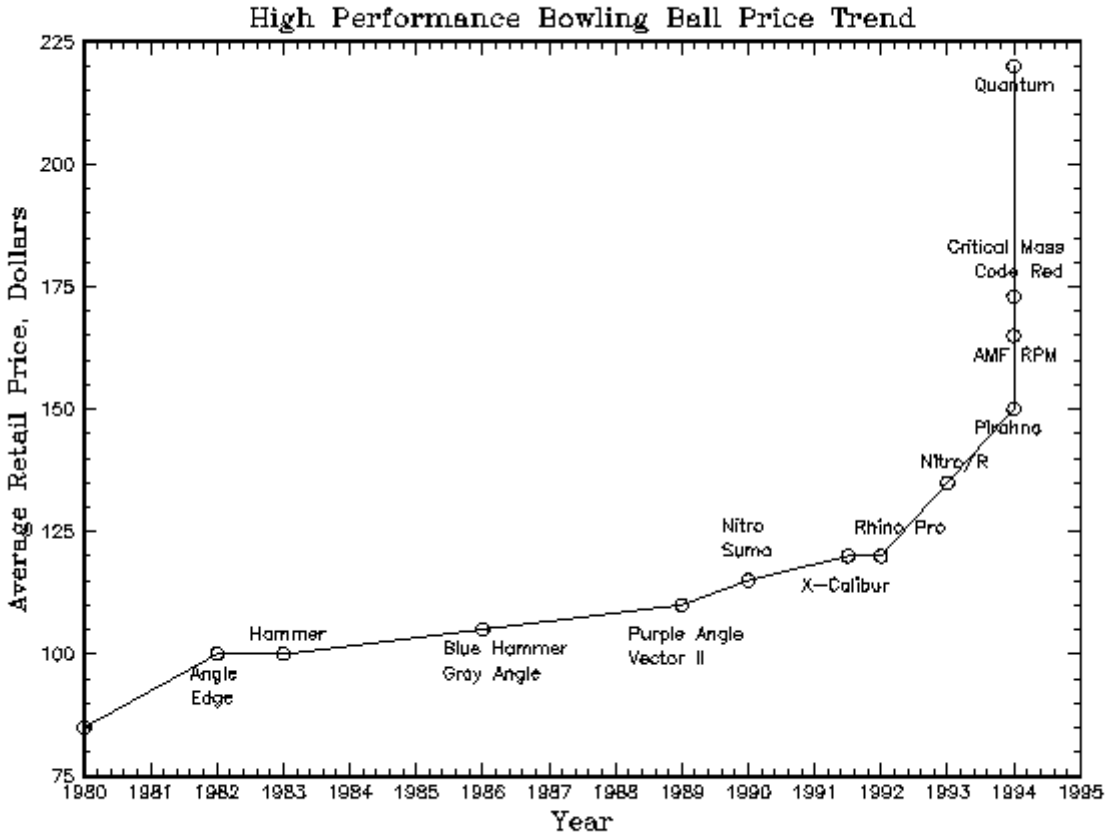


- Must *hook* the ball in order to create the large entry angles necessary to score
- Hook is created by:
  - friction between ball and oil/lane surface
  - rotational kinematics of ball, including the (*non-diagonal*) moment of inertia tensor

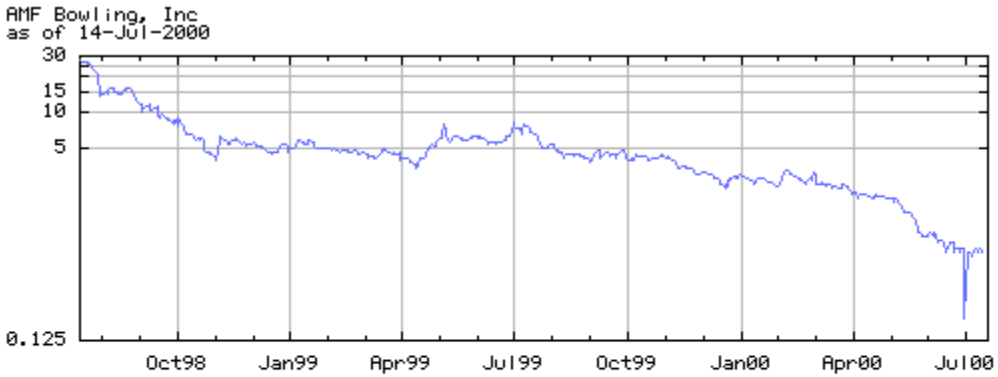
Rotational Kinematics

- Earth-Centered-Inertial (ECI) and Ball-Centered-Rotational (BCR) coordinate systems
- Pre-1990 bowling:
  - $\underline{\mathbf{I}}$ (moment of Inertia) is diagonal
  - $\hat{\omega}$ (rotational axis vector) is constant in BCR
  - equations of motion relatively simple
- Post-1990 bowling:
  - all three of these have changed ...

Capitalism at Work!



Capitalism gone Wrong?



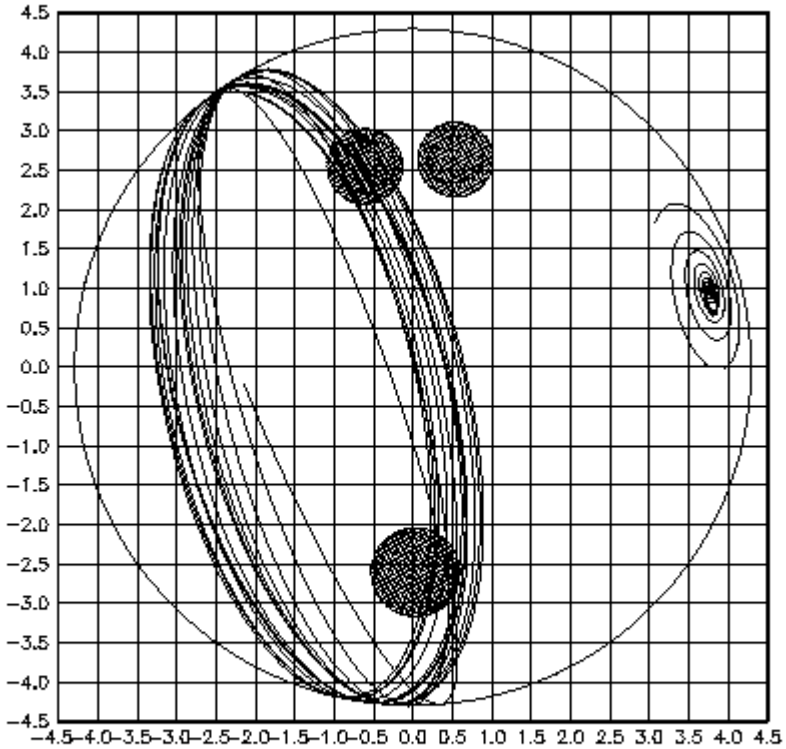
Mathematics

- ECI-to-BCR is described by orthogonal 3x3 rotation matrix:
  - $\vec{p}_{ECI} = Q(t)\,\vec{q}_{BCR}$
- Rotational axis defined by:
  - $\dot{Q}\,\vec{\omega}_B = 0$ (in BCR)
  - $\dot{Q}\,Q^t\,\vec{\omega}_E = 0$ (in ECR)
- Because Q is orthogonal, $\dot{Q}Q^t$ is antisymmetric
  - one zero and two imaginary eigenvalues
  - $\hat{\omega}_E$: eigenvector corresponding to null eigenvalue

Friction

- Linear model works for "older" balls
  - $F_f = - \mu (M g) \hat{V}_c$ friction at *contact* point
  - $\vec{V}_c = \vec{V} - a \dot{Q} Q^t \hat{z}$ velocity at *contact* point
- Post-1991 balls, "reactive resin," must be modeled with non-linear $F_f(V_c)$
  - thermoset elastomers with liquid polymer suspended is surface (*bleed* when hot)

Ball Track "Flare"



Positive Axis Point:

Intersection of ω_B with ball's surface; initial value defined by drilling of grip holes relative to bowler's wrist position at release.

- Flare = Distance track moves across ball, can be 1/2 the ball or more!