Doing Research on Purpose:
Explorations in Closed-Loop Cognition

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Outline

- Purpose in Psychology
- Closed-Loop Systems
- Research Methods
- Research on Purpose

Purpose in Psychology

Purpose in Scientific Psychology

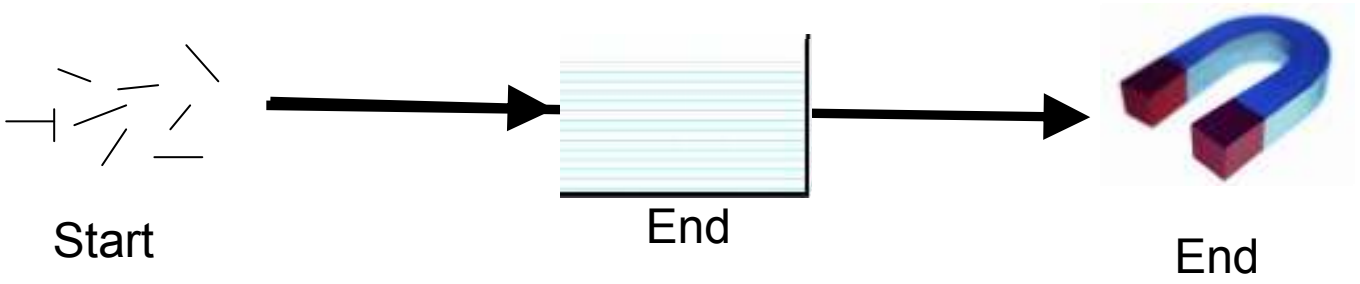
- Definition of purpose: An intended or desired end
- Purpose was a central concept in the early development of scientific psychology
- William James saw purpose as what distinguishes the behavior of living from that of non-living things
  - Behavior of non-living things has a cause
  - Behavior of living things has a purpose
- James dramatizes this observation in first pages of the *Principles of Psychology* (1890)

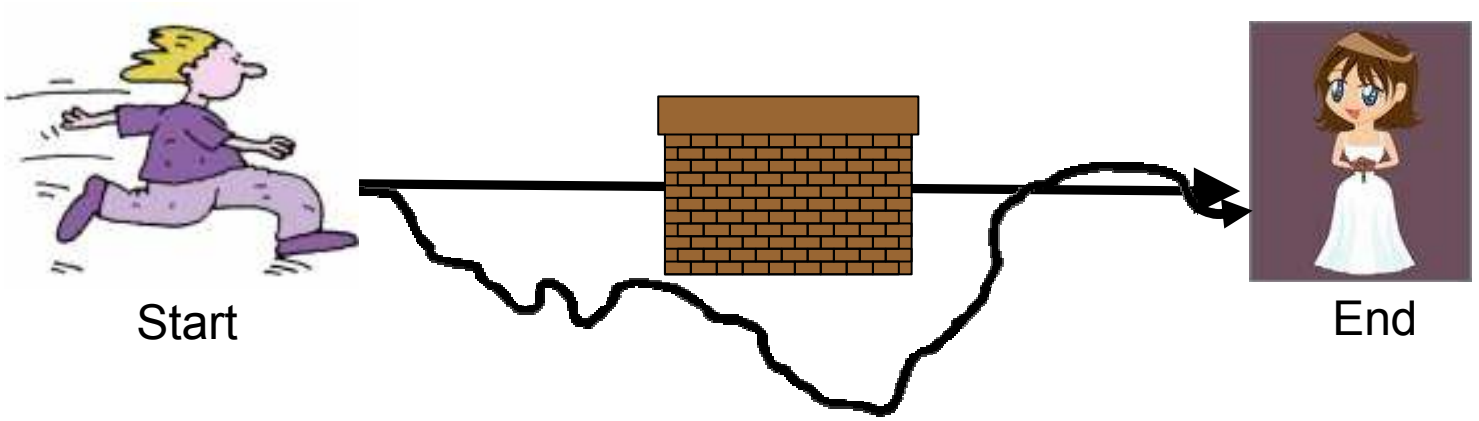
Romeo and the Filings

Romeo wants Juliet as filings want a magnet; and if no obstacles intervene he moves toward her by as straight a line as they. But Romeo and Juliet, if a wall be built between them, do not remain idiotically pressing their faces against its opposite sides like the magnet and the filings with the [obstructing] card. Romeo soon finds a circuitous way, by scaling the wall or otherwise, of touching Juliet's lips directly. With the filings the path is fixed; whether it reaches the end depends on accidents. With the lover it is the end which is fixed; the path may be modified indefinitely.

-- William James, *Principles of Psychology*, 1890

Caused versus Purposeful Behavior





Revealing Purpose

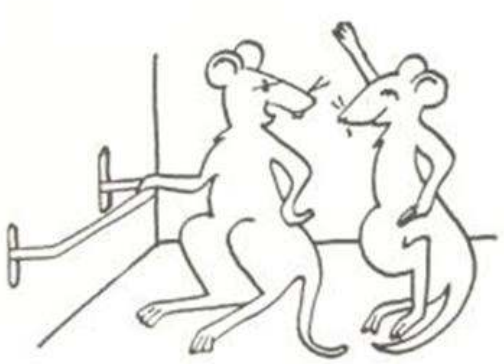
- Purposeful and caused behavior can look the same
- In both, behavior appears to be caused by external stimulus
  - Filings' behavior appears to be caused by magnet
  - Romeo's behavior appears to be caused by sight of Juliet
- James' insight
  - Purpose is revealed by *disturbances* (like the obstructing card)
  - Purpose is seen when means (actions) vary appropriately so that end is produced despite disturbances

The Problem With Purpose

- James knew how to reveal the purpose
- But he could not explain how purposeful behavior could happen
- Purposeful behavior seems to violate laws of cause and effect
  - In particular, the law that says cause should precede effect
- In purposeful behavior, a future end seems to determine the present means that are used to achieve it
- Purpose was, therefore, deemed unscientific

Purpose Lost

- Focus on purpose nearly disappeared with onset of behaviorism
  - Psychology should be like other sciences
  - Behavior is cause – effect process
- Tolman's "Purposive Psychology" was an exception
  - Brilliant demonstrations
  - Weak explanations
- By and large, purpose was scorned



Boy, have I got this guy conditioned! Every time I press the bar he drops in a piece of food.

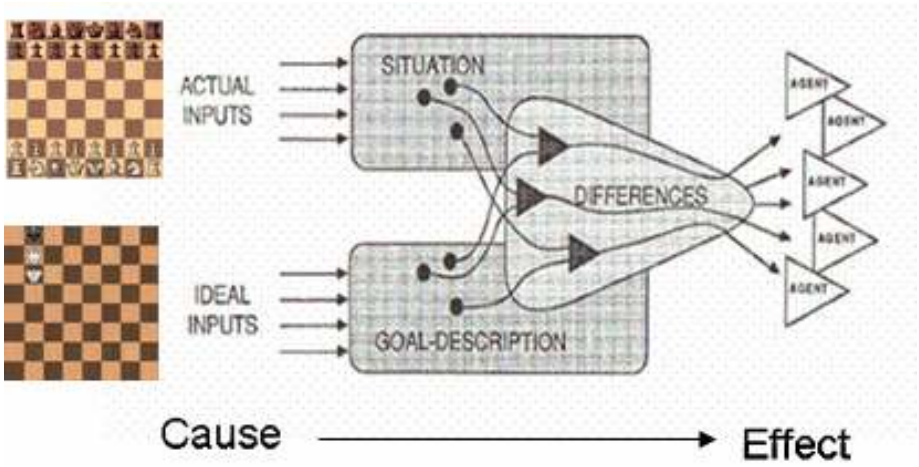
Purpose Redux

- Cognitive Revolution
  - Made purpose respectable again
- Made possible by development of purposeful computer programs
  - GPS
  - Chess
- These programs worked by acting to achieve pre-specified ends
  - Goals and subgoals
- This proved that purposeful behavior could be produced by mechanistic systems (computers)

Newell and Simon study chess at RAND

Causal Model of Purpose

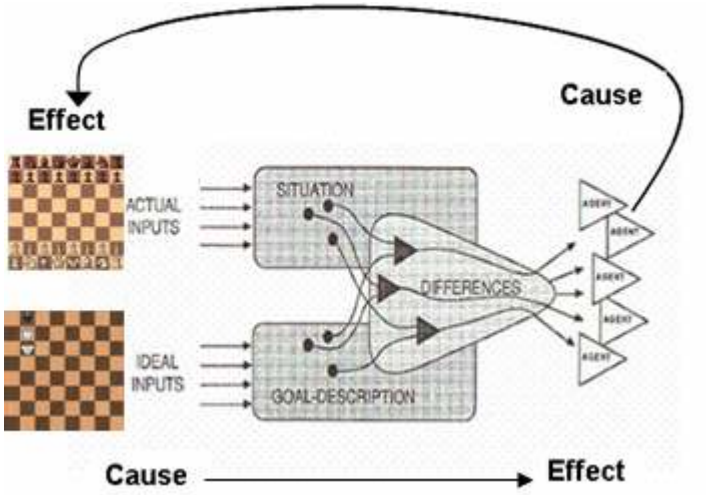
- Nevertheless, cognitive psychology adopted causal model of purpose
- Diagrams of purposeful programs (and the behaviorist zeitgeist?) made purposeful behavior look like open-loop causal process
- In chess, for example, board position is cause, move is effect



- Research on purpose looked for the causes of purposeful behavior
- Example is Chase and Simon's study of memory for board positions
  - They conclude that board positions (inputs) cause moves (outputs) in chess

Closed-Loop Causality

- Purposeful behavior is actually closed-loop
- In chess playing
  - Board positions (inputs) cause moves (outputs)
  - Moves (outputs) cause board positions (inputs)`

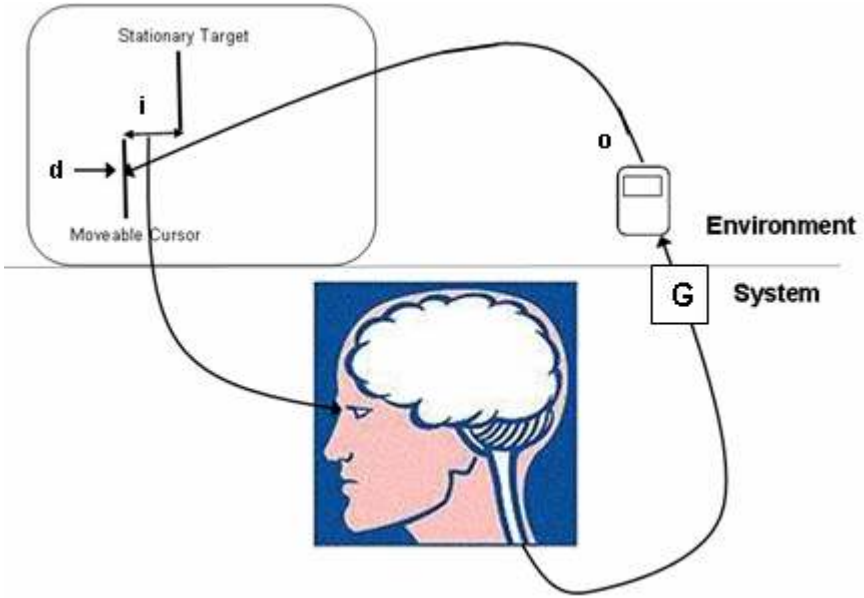


- This fact has been recognized by cognitive scientists
- Does this make a difference?
- My research has been aimed at showing that it does!

Closed-Loop Systems

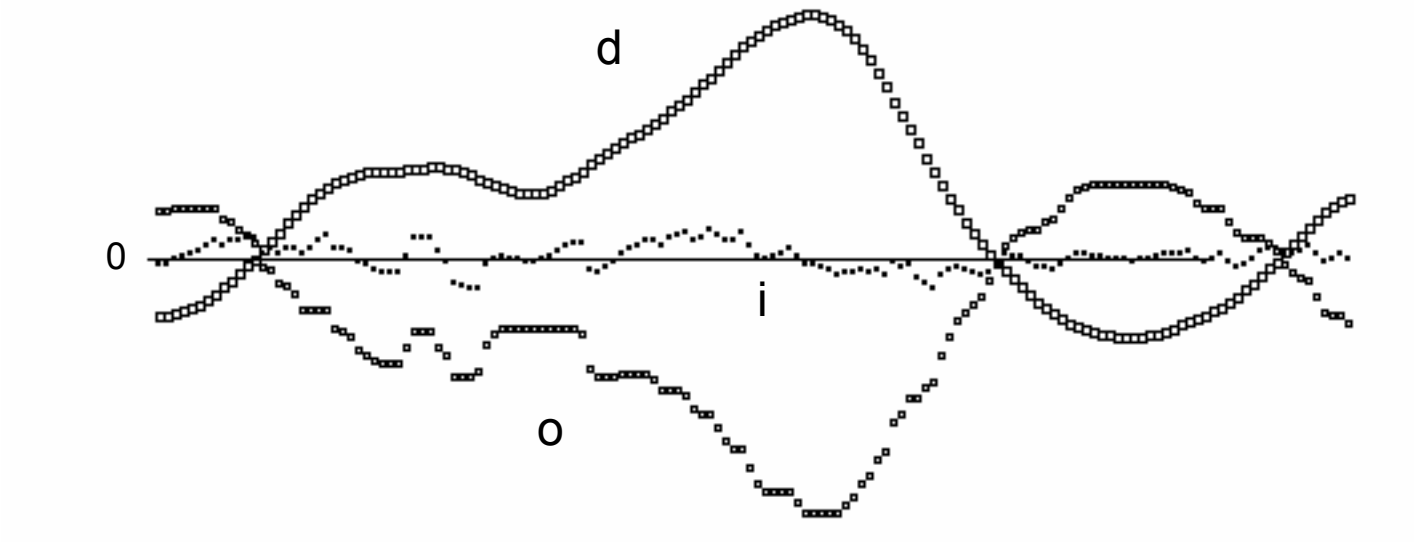
Purpose in a Closed-Loop

- Compensatory tracking
- Purpose is to keep cursor on target
  - Keep i = 0
- This purpose is carried out in closed-loop
- Causal model
  - Input, i, causes the output, o, that achieves the purpose of keeping cursor on target



The Cause of Purposeful Behavior

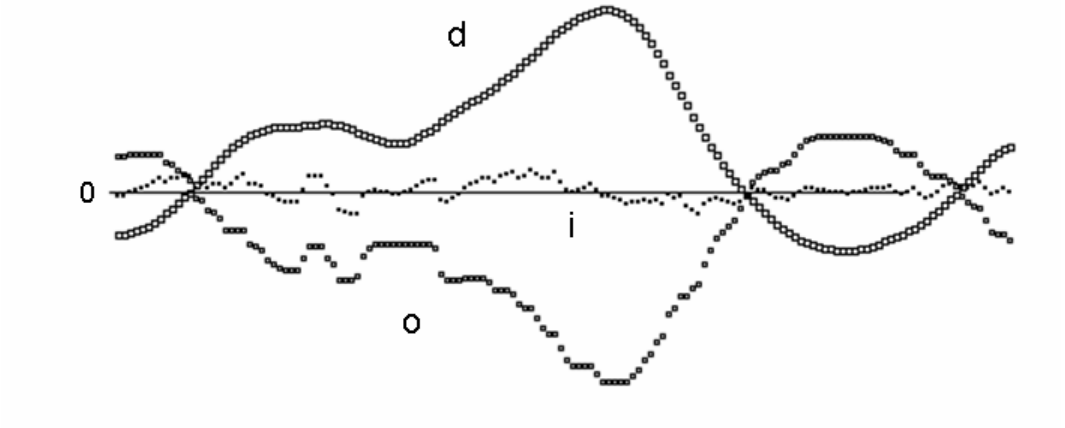
- Low correlation between input, i and output, o, is problem for causal model of purpose



Correlation between i and o = .03
Correlation between i and d = .12
Correlation between d and o = .991

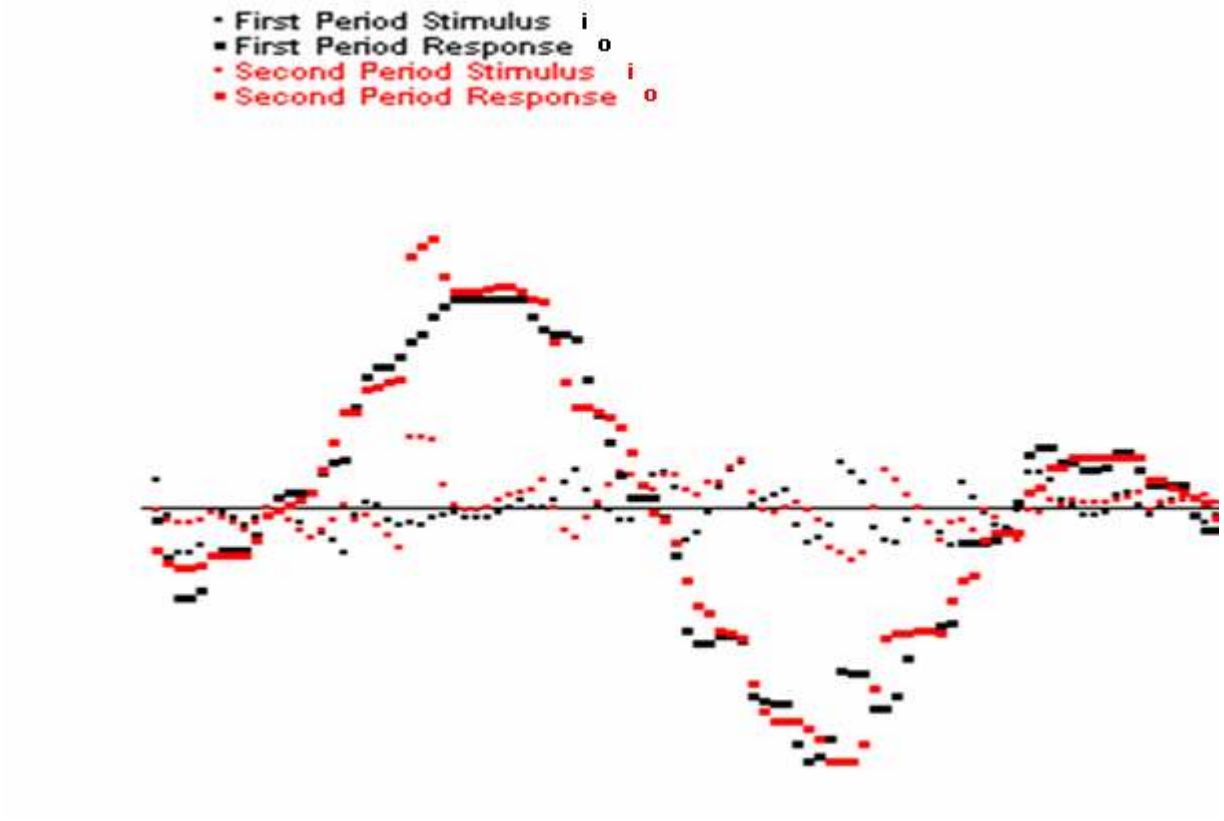
Online experiment at http://www.mindreadings.com/ControlDemo/BasicTrack.html

What is the Cause?



- Many possibilities, including
  - Delayed effect of input, i
  - Non-linear function of i
- Tested all possibilities in repeated disturbance experiment
- High correlation between disturbance, d, and output, o, means repeating disturbance will repeat output
- If cause of output is something about input then:
  - Predict high correlation between input on two trials when same output occurs

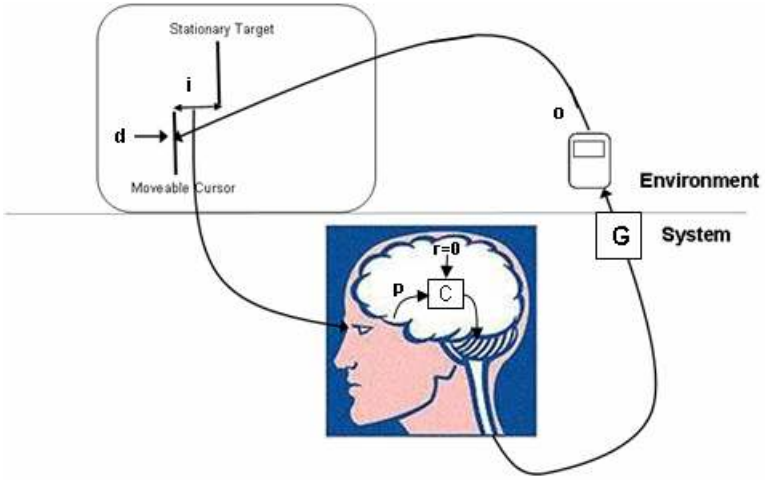
Something in the Way it Moves?



Correlation between first and second period o = .97
Correlation between first and second period i = .03

Online experiment at http://www.mindreadings.com/ControlDemo/Cause.html

Organization of Closed-Loop Systems



- Input, i, is *simultaneously a* cause and effect of output, o
- Closed-loop system defined by two simultaneous equations
  1. System: o = G (r – p)
     - Reference, r, is offset in system that makes feedback negative
     - Effect of input on output opposite to effect of output on input
  2. Environment: p = o + d

Behavior of Closed-Loop Systems

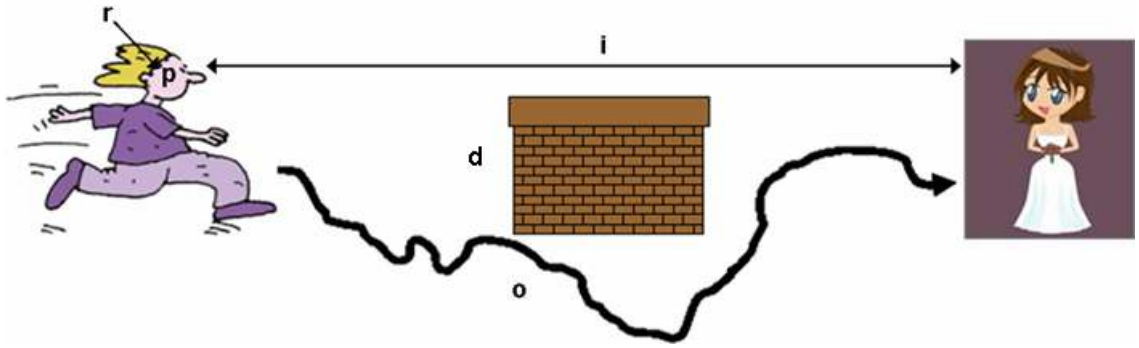
- Solving simultaneous equations with output gain G>>1 we get the following steady state solutions for system behavior:
  - $p \approx r$ (1)
  - $o \approx - d$ (2)
- Equation (1) says:
  - Perceptual variable is kept in agent-defined reference state
- Equation (2) says:
  - System achieves this by acting to oppose disturbances to perceptual variable
- This is what is happening in tracking task
- This process is called **control**

Closed-Loop Control

- A closed-loop negative feedback system (with high gain, G) controls
  - Acts to bring a perceptual variable, p, to a pre-specified end, r
  - Varies means, o, as necessary to oppose disturbances, d
- This sounds a lot like purposeful behavior
- In fact, what James saw as purposeful behavior was the process of control

Control As Purpose

- Control and purposeful behavior
  - In both, agent acts to bring a variable to a pre-specified end state while working to oppose disturbances
  - Reference, r, is present time representation of intended end (viz., purpose)



- Romeo's purpose is to get close to Juliet
- Romeo is controlling his distance, i, from Juliet
  - He acts to bring a perception, p, of this distance to a pre-specified end, r
  - He varies means, o, as necessary to oppose disturbances, d

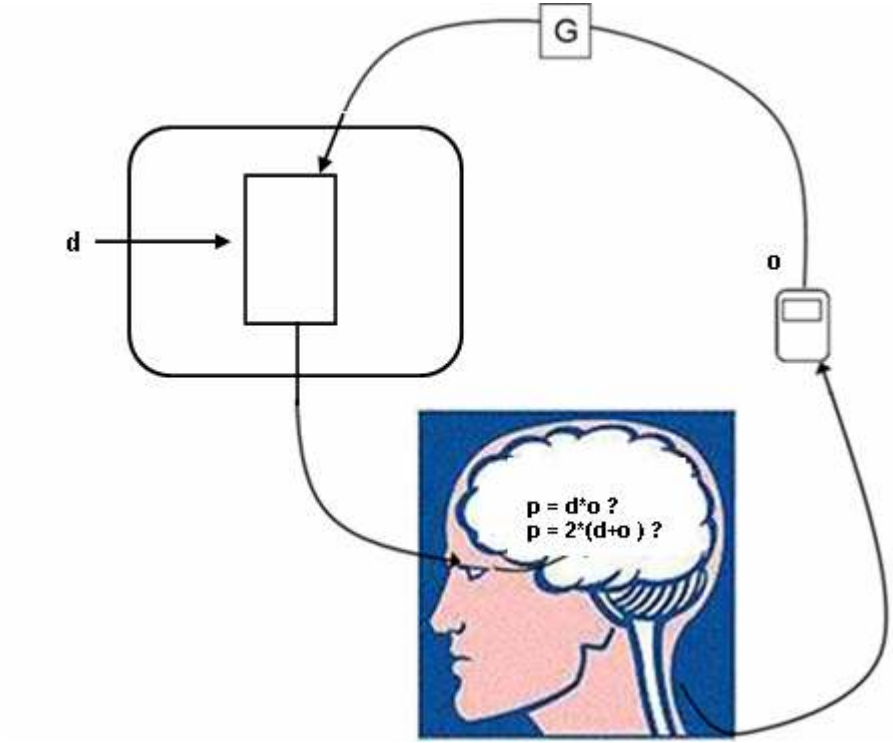
Understanding Purposeful Behavior (Control)

- In order to understand purposeful behavior you have to know what perceptual variables are being controlling
  - Controlled variables
- Take chess for example
  - Moves are a mystery until you know what perceptual variables the player is trying to control
  - Possible controlled variables in chess
    - Control of center
    - Protection of king
    - Development of pieces
  - If you know which of these variables is being controlled you can understand why each move is made
- Research on purpose is aimed at discovering ***controlled variables***

Research Methods

Detecting Controlled Variables

- Keep size of rectangle constant
- Two possible controlled variables
  - Area = d * o
  - Perimeter = 2 *(d + o)
- How do you tell which perception is being controlled?



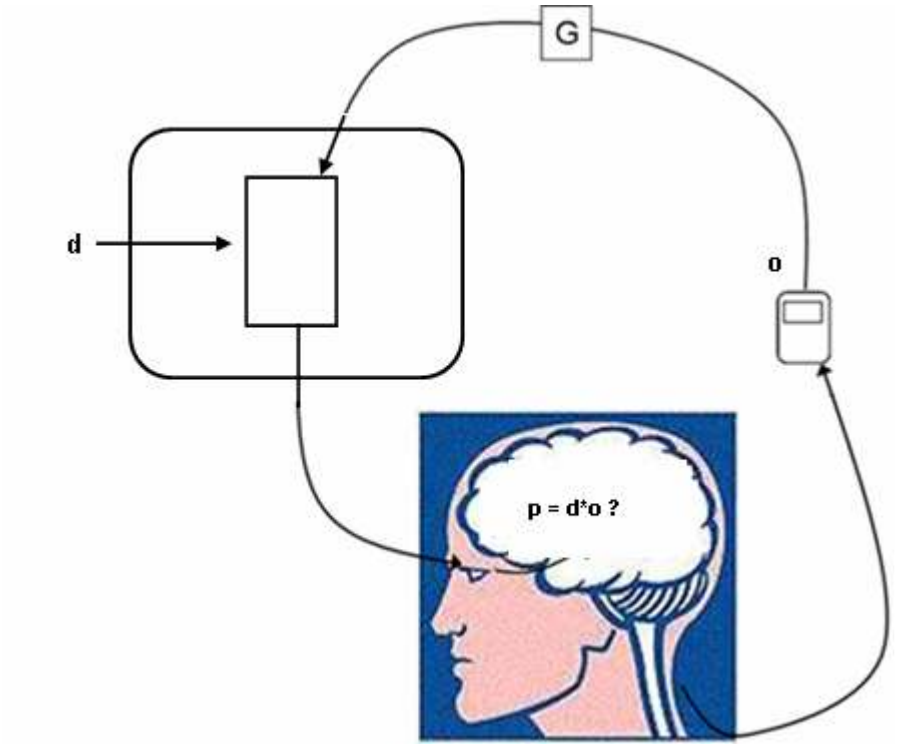
Test for Controlled Variables: "The Test"

- Basic methodology of research on purpose
- Steps in The Test:

1) Develop hypothesis about the variable being controlled
2) Determine how disturbances would affect hypothetical controlled variable if it were *not* controlled
3) Apply a disturbance
4) Monitor hypothetical controlled variable to see if the disturbance has expected effect
5) If so, variable is not controlled; return to step 1
6) Else the variable might be under control; return to step 3 with new disturbance
7) Continue process until effect of several different disturbances can be correctly predicted

Test for Control of "Size"

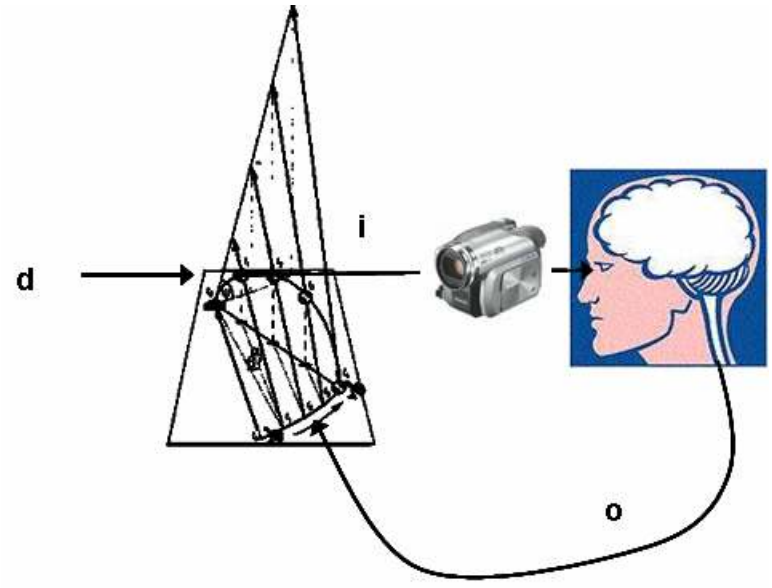
- Start with hypothesis that area is under control
- Monitor variable (d*o) while it is being disturbed
- If disturbance has expected effect, start over with new hypothesis
- If not, try new disturbance and continue until effect of several different disturbances can be correctly predicted
- Essential aspect of the test
  - Monitor hypothetical controlled variable while it is being disturbed



Research on Purpose

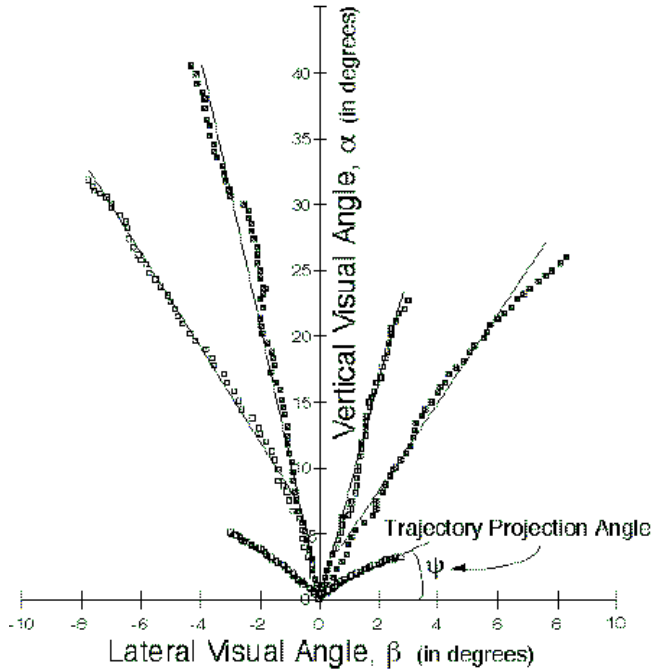
Monitoring a Possible Controlled Variable

- Found article that seemed to involve a test for a controlled variable
  - McBeath, M. K., Shaffer, D. M., & Kaiser, M. K. (1995). How baseball outfielders determine where to run to catch fly balls. *Science, 268,* 569–573.
- Researchers use clever technique to monitor status of potential controlled variable while it was being disturbed
  - Shoulder mounted camera captured what outfielder saw when catching fly ball



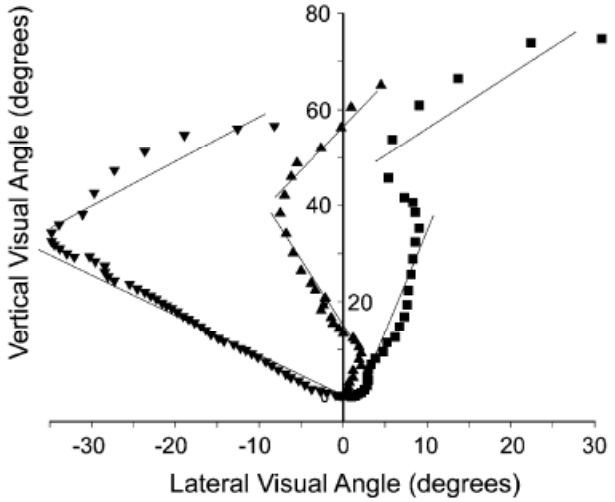
Catching a Fly Ball: The Fielder's View

- Observed straight line optical trajectories that were not expected given parabolic trajectory of ball
- Fielder seems to be running in order to maintain a linear optical trajectory (LOT)
  - Purpose is to maintain LOT
- Conclusion was that LOT is the variable controlled when catching a fly ball



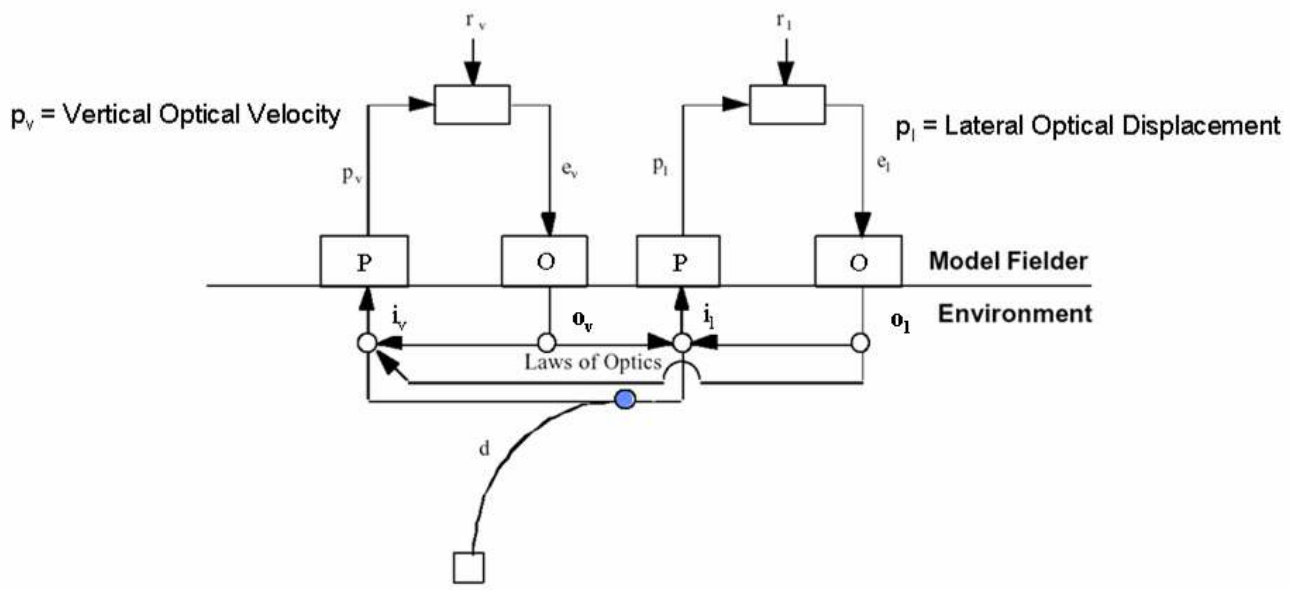
A Disturbing Possibility

- LOT is maintained in face of parabolic trajectory disturbance
- Must try other disturbances to make sure LOT is actually controlled
- So the research went to the dogs
  - Frisbee trajectory is excellent disturbance
  - If LOT is controlled optical trajectory should still be straight line
  - Result is non-linear



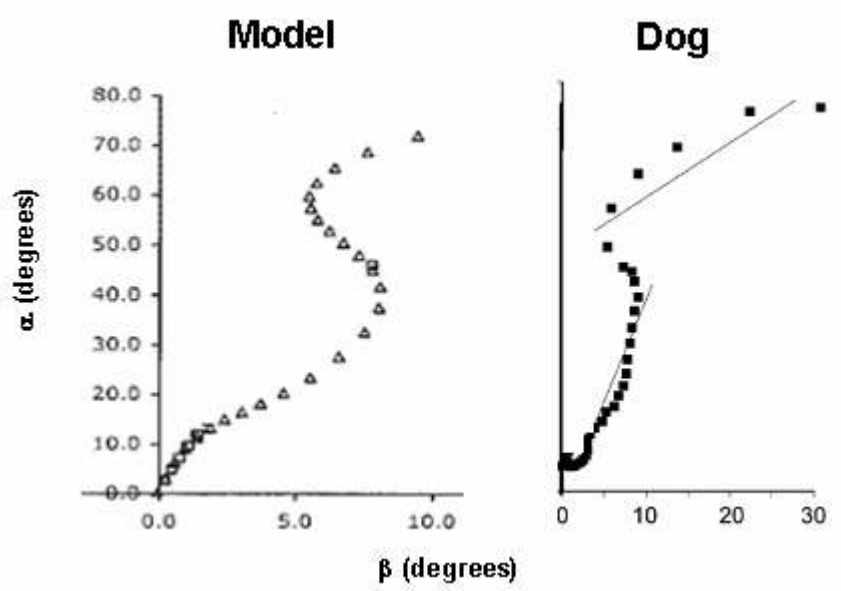
Of Dogs and Models

- Disturbing result suggests that LOT is not controlled
- Researchers should have rejected LOT hypothesis
- Instead, they interpreted results in terms of linear segments
- Alternative hypothesis is that observed trajectories are observed because fielder controls two variables
  - Vertical optical velocity
  - Lateral displacement

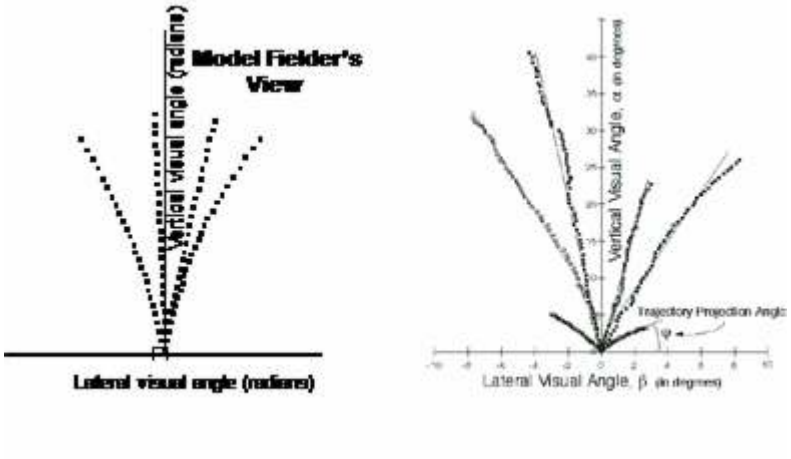


Model Behavior

- Frisbee Data

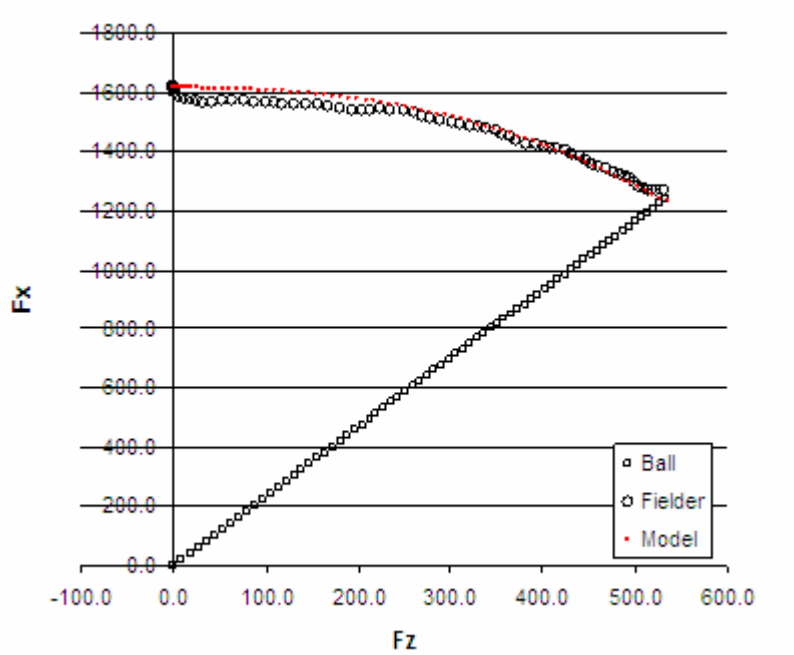


- Original Data



Model Fit to Running Behavior

- Fit model to data obtained by Peter McLeod and his student, Nick Reed, at Oxford University
- They measured movement of fielder **and** trajectory of ball
- Fielder model controls perceptions of the known trajectories
- Produces movements that are very close to measured movements



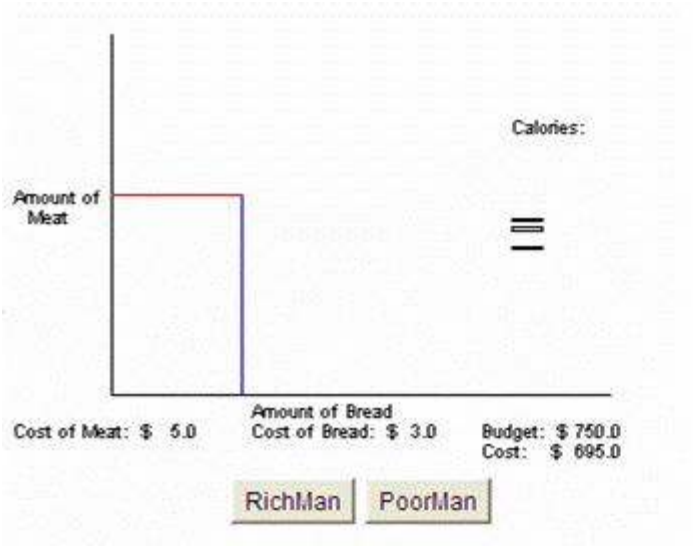
Economic Behavior

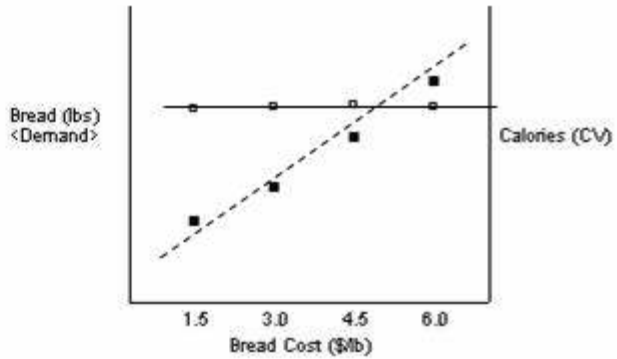
- Consumption is supposed to vary inversely with cost
  - Increase in price should produce decrease in consumption of good
  - The “demand curve”
- There is anecdotal (and now some real*) evidence that sometimes consumption varies directly with cost
  - Increase in price of good produces increase in consumption
  - Called “Giffen behavior”
- Can be explained in terms of controlled variables
  - Control for caloric intake
  - Control of savings (>=0)

* Jensen,. R. T and Miller, N. H. (2007) Giffen Behavior: Theory And Evidence, Working Paper 13243, National Bureau Of Economic Research, Cambridge, MA

Giffen Behavior

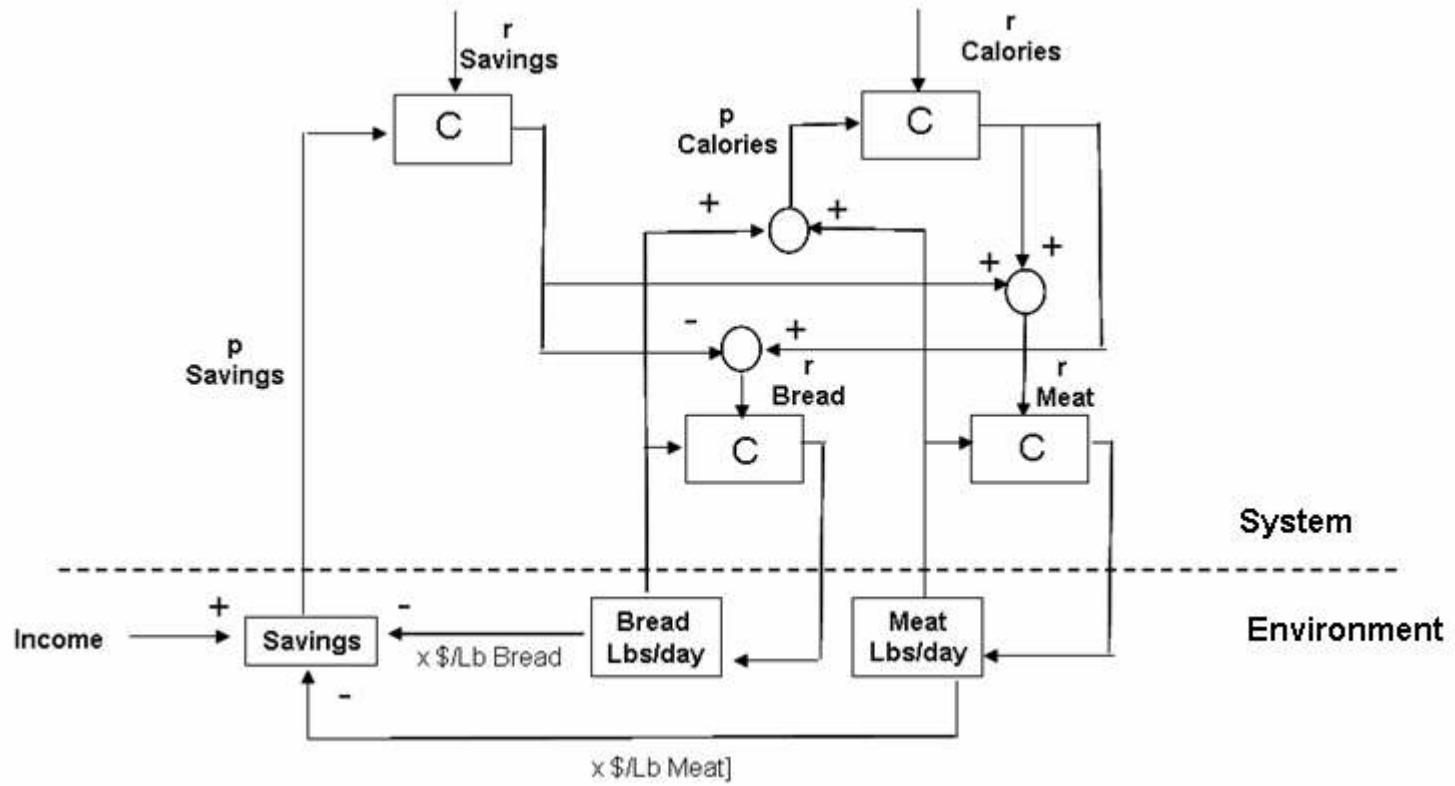
- Computer demo lets person purchase meat (expensive good) and bread (inexpensive good) to control caloric input
- Do this in context of large or small budget
- Results with small budget show that consumption of less expensive good must increase as price of that good increases





See demo at http://www.mindreadings.com/ControlDemo/Economics.html

Closed Loop Model of Economic Choice



- Two level hierarchical control model
  - Two higher level systems control for savings and calories
  - Do this by manipulating reference (goals) of two lower level systems
  - One lower level system controls for meat consumption, the other for bread consumption

Conclusions

- Research on purpose suggests new directions for cognitive science
  - Research aimed at determining perceptual variables people control as they carry out various activities
- Also suggests new view of the role of the brain in behavior
  - Brain is seen as
    - Source of specifications (references) for perceptual input
    - Location of mechanism for comparing input to specifications
    - Source of outputs that keep inputs “up to spec”

Derivation of Closed-Loop Behavior

1. $o = G(r - p)$

2. $p = o + d$ BASIC STEADY-STATE EQUATIONS SIMPLIFIED

Solve for output quantity o:

3. $o = G[r - (o+d)] = Gr - Go - Gd$

4. $o + Go = Gr - Gd$

5. $$o = \frac{Gr - Gd}{1 + G} = \frac{G}{1+G}(r - d)$$

Let G increase without limit so $G/(1 + G) \sim 1$

6. $o \sim r - d$

Solve for p, you get

$p = o + d$

$p = G(r - p) + d = Gr - Gp + d$

$p + Gp = Gr + d$

$$p = \frac{Gr}{1 + G} + \frac{d}{1 + G}$$

Letting G go to infinity,

$p \sim r$