Human-Information Discourse in Visual Analytics or What Friedrich Bessel Can Teach Us About Interaction Design

Brian Fisher and John Dill

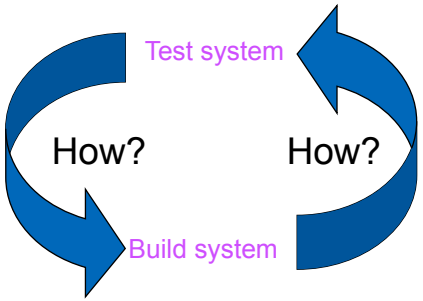
Academic Background

- Molecular Biology, Medical Biophysics, Hiram/CWRU
- Cognitive Neuroscience, Experimental Psychology, UCSC
  - Dissertation used Fuzzy Logic Model of Perception to fit human data in categorization and localization of bimodal stimuli presented on hemicylindrical screen
- Human-Information Interaction
  - UWO, Inst. for Robotics & Intelligent Systems, Cogsci
  - Rutgers Centre for Cognitive Science
  - SFU, IRIS 2, HFIT
  - UBC Media And Graphics Interdisciplinary Centre
  - SFU School of Interactive Arts and Technology

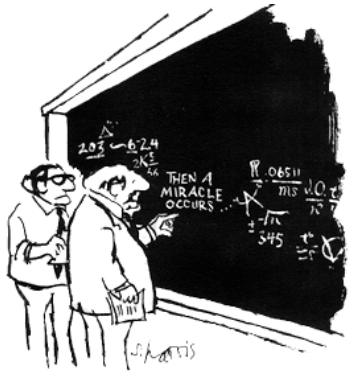
From science to design--- My early career was science, methods focused on statistical, computer, and math modeling

Quasi-immersive display
Now I work in a design school

Role of science in design?



Spiral from mockup to system



"I think you should be more explicit here in step two."

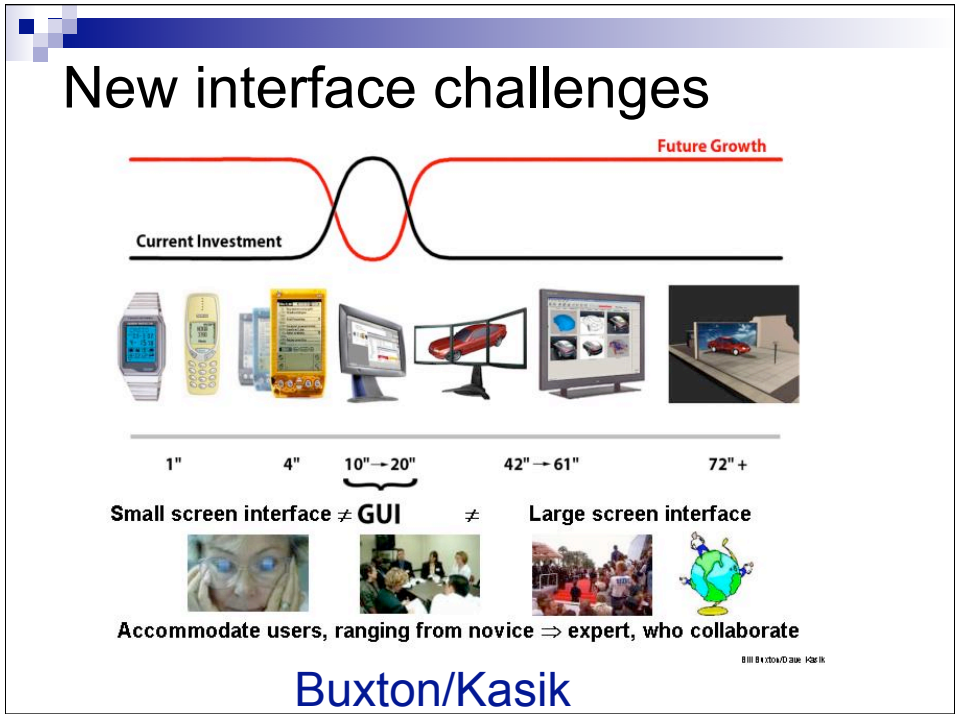
I have used the same methods throughout, but the application has changed quite a bit. what I do is still designed to produce knowledge, but the nature of the questions has changed

I'll argue that the approach I am taking is one way of addressing a crisis in the design of information systems.

New challenges for designers

- Interactive technology is immersive, multimodal, and ubiquitous
  - Must understand impact of design on perceptual systems
- Goals shift from doing work to augmenting human abilities & experience
  - "New media" art and entertainment
  - Social software for human communication
  - Learning & decision support for cognitive processes

The crisis arises both from technology "push"-- increased complexity of information and ways of processsing and in particular presenting it to users and from application "pull"-- increased range of applications and roles of technology, with the accompanying increase in diversity of the user population



The space of possible designs has exploded, while the criteria for creating and evaluating design have become more difficult to identify. The number and configuration of screens has outstripped our research on how they can be used

The range of users has increased from a few professionals to a wide range, and they may use the technology in collaboration

Moore's Law vs. Darwin's Law

- Transistor density doubles every 24 months
- Disk density doubles every 12 months
- Brain volume doubles every 3 x10^7 months

This makes sense, given the nature of human abilities

New roles, new problems

- Diversity of users (D.Kasik, Boeing)
  - "We want to derive more value for 3D model data outside engineering... Examples: 3D for assembly instructions, animation for maintenance procedures, bids from suppliers."
- Individual differences (R.Smith, GM)
  - "For a smaller number of individuals.. some features are seen to be inappropriately large or small, they may appear at the wrong distance, the three-dimensional space inside the vehicle may appear distorted…"
- Problems with perceptual abilities of more diverse user population

Here in a nutshell are two recent research questions that have led to industry-sponsored projects for my colleagues and myself
Neither of these deal with technology per se, rather they pertain to the perceptual and cognitive uses of technology

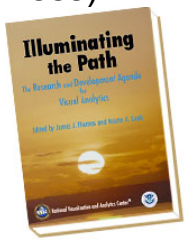
New applications, new problems

- Visual Analytics: “The science of analytical reasoning facilitated by interactive visual interfaces”
- Support understanding implications of data
  - Synthesize information & derive insight from massive, dynamic, ambiguous, & conflicting data
  - Detect the expected & discover the unexpected
  - Build timely, defensible, & understandable assessments
  - Communicate assessments effectively for action.

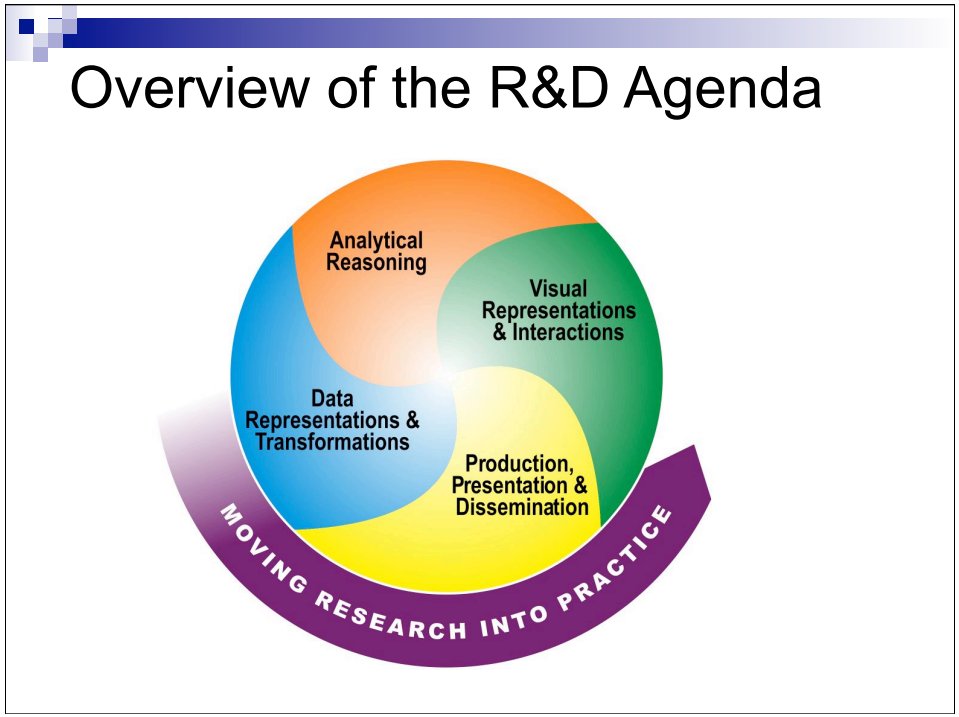
Some of you will recognize this as a thread that has run through the history of computing from Vannevar Bush’s Memex through Douglas Engelbart’s OLS. Engelbart and his colleagues at SRI implemented the first videoconferencing, hyperlinking, the mouse, windows, cscw etc. in the 1960s in order to augment human cognitive ability to solve the difficult problems of the day.

Visual Analytics R&D Agenda

- R&D Agenda Panel
  - Muti-sector, multi-disciplinary
  - Input from researchers, developers, agencies
  - Defined VA ("science of analytic reasoning…")
  - Identified key research foci, problem areas & recommendations for R&D process
- Published as "Illuminating the Path" (IEEE Press)
  - Inform CFPs from ARIVA, NSF
  - Important in PacRim & EU R&D efforts



R&D Agenda Panel of top scientists who defined the field and the research plan that would drive the US R&D efforts
Includes direct funding, also ARIVA and NSF CFPs
Picked up internationally e.g. a German group we are talking with have a proposal $21.6M/6 yr (Keim).
VA in 7th framework, expected to be > 100M Euros



Really starting with science, both the cognitive science of human reasoning and the emerging “interaction science” of visual representations and how people interact with them

Data representations and transformations are still important of course

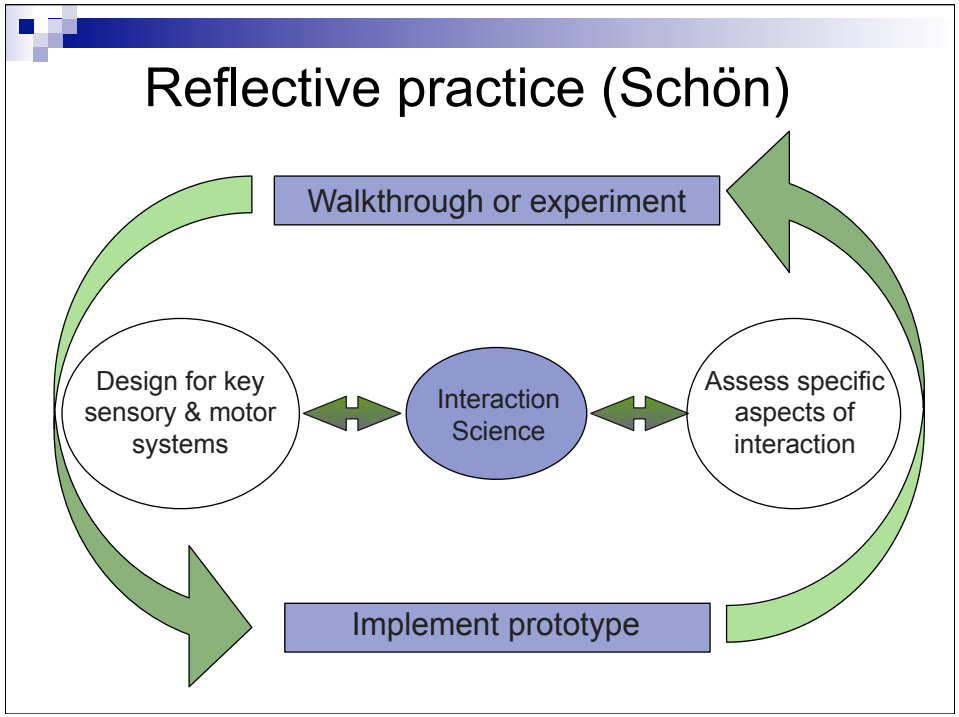
A good deal of emphasis is placed on moving from research to practice as well as building a base for ongoing VA development-- training plans, Masters programs in VA, basic research support etc.

What kind of science is VA?

"This science must be built on integrated perceptual and cognitive theories that embrace the dynamic interaction between cognition, perception, and action. It must provide insight on fundamental cognitive concepts such as attention and memory. It must build basic knowledge about the psychological foundations of concepts such as 'meaning,' 'flow,' 'confidence,' and 'abstraction.' "

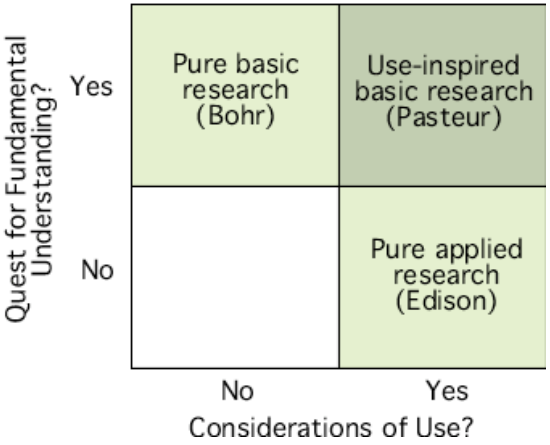
"Illuminating the Path" (IEEE Press)

The panel defines VA as a science, so we may ask what kind of science it is? Given that their interest is in the end in applications, how does the science interact with application design?



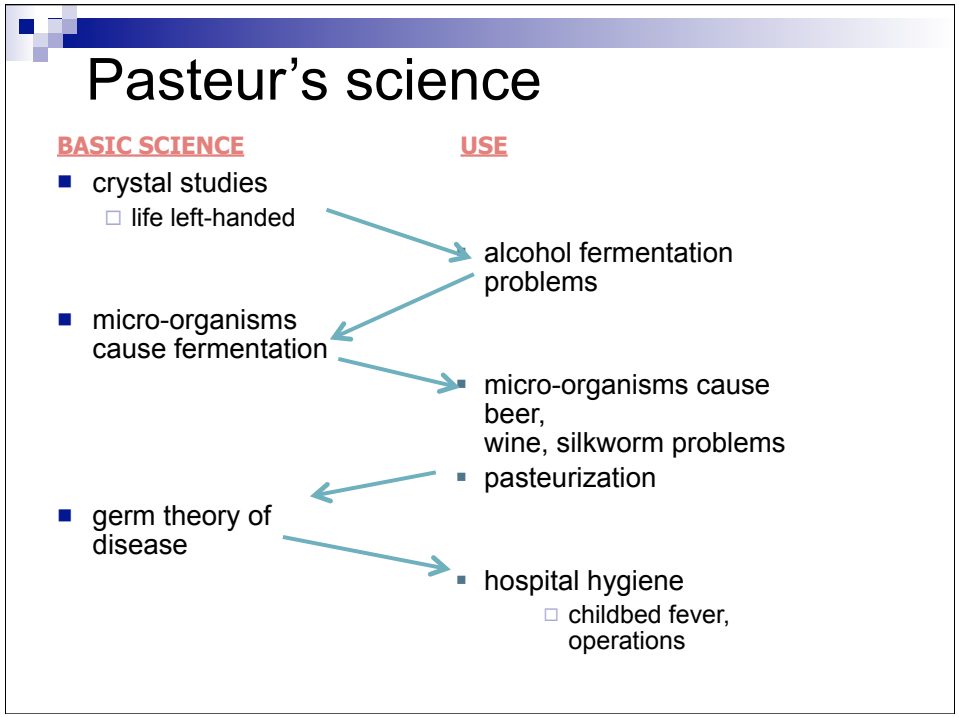
One casualty of the move to more complex interactive environments that “download” processing to perceptual systems may be the basic spiral model of design. The larger design space of multimodal and immersive environments makes the design stage more difficult-- if designers themselves lack valid intuitions about the impact of their designs on users’ perceptual systems how can they design them effectively? Similarly, what constitutes a test of the perceptual interaction of a given design?

Pasteur's Quadrant (Stokes)

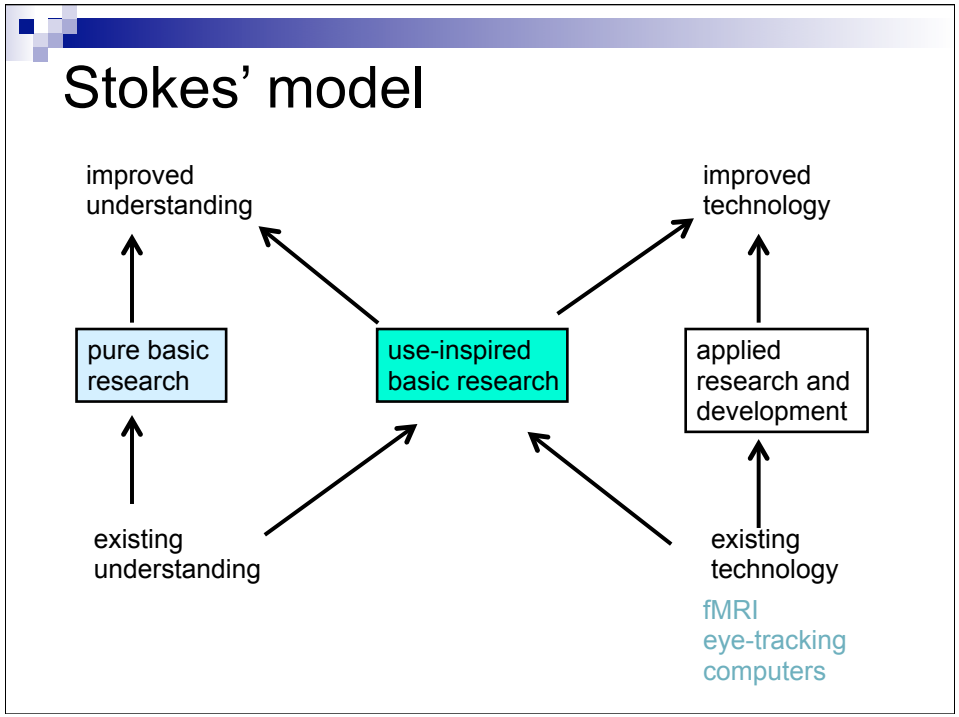


"Il n'existe pas une catégorie de sciences auxquelles on puisse donner le nom de sciences appliquées. Il y a la science et les applications de la science, liées entre elles comme le fruit à l'arbre qui l'a porté"

If we look at the history of applied science we find examples of what Stokes called "Oriented basic research"-- research whose goal it is to produce knowledge that may be of use. This decouples our usual confounding of the source of the question (curiosity vs. Need-to know) and the nature of the produce of research (knowledge in both cases)



I borrowed this slide from Stu Card, it shows the pattern of research



Another of Stu's slides, showing use-inspired basic research as it links science and application. We typically concentrate (an government funds) the vertical paths only

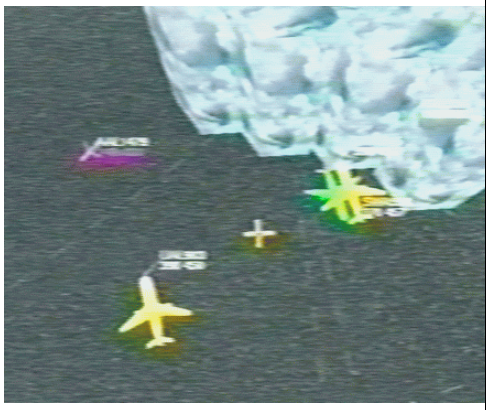
Research approach

- Decompose task based on cognitive architecture
- Identify interaction challenges to cognitive processing modules
- Devise “toy world” test of that module’s robustness to challenge
  - Use-inspired basic research
  - Research interaction, not the mind
- Model data for quantitative prediction

My group has built an approach to use-inspired basic research in human-information discourse
It takes a cognitive systems approach,

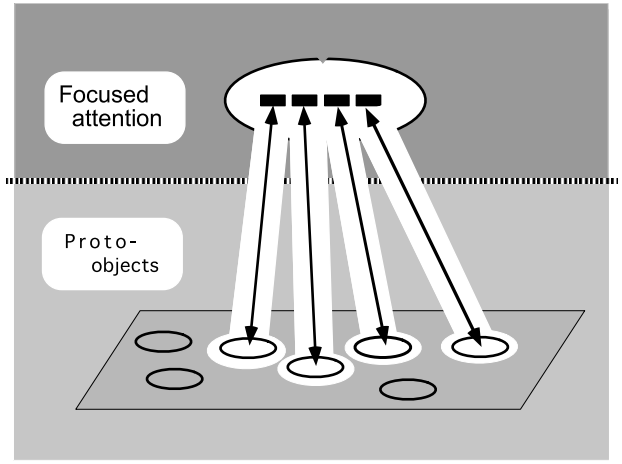
Air traffic control research

- Free Flight ATC “fishtank” projection
- Change camera position for better view
- How will global motion affect tracking?



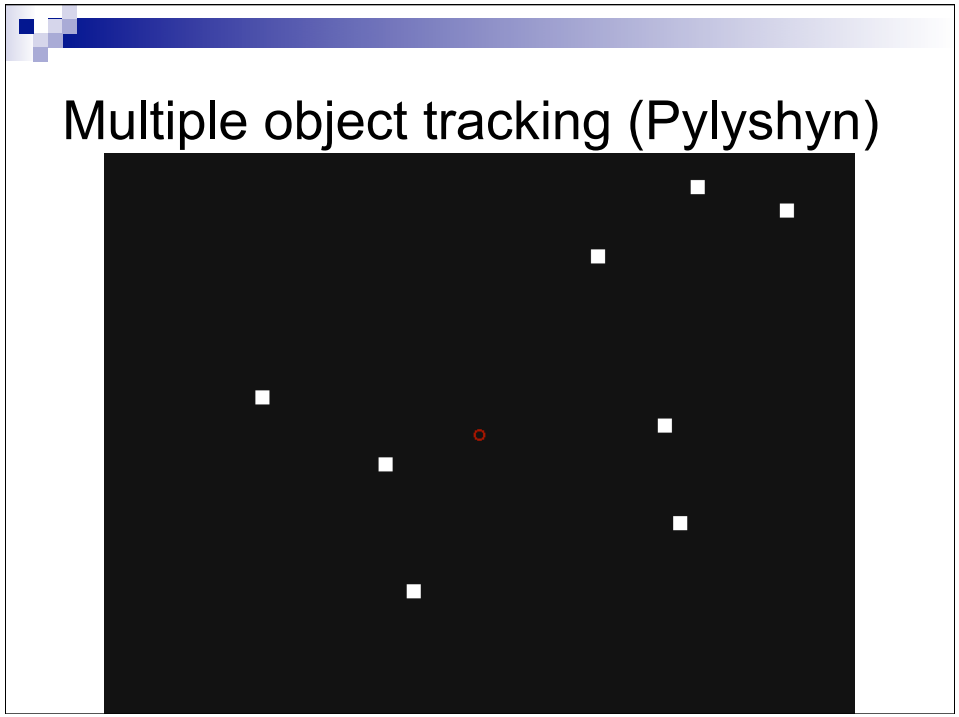
An example from our previous NSERC Strategic grant with Hughes Raytheon Labs looked at new ATC technology

FINST theory of spatial indexing

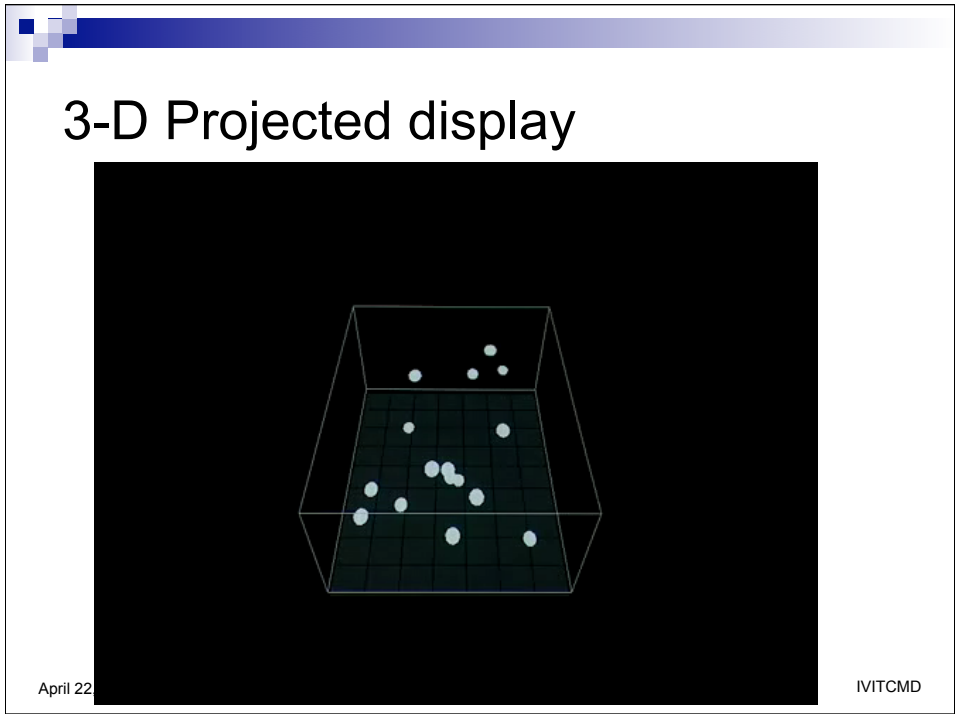


We know that there is a recently discovered attentional mechanism called a FINST that limits our ability to parse visual scenes.

Feedback from higher-level areas allows a small number of proto-objects to be stabilized.

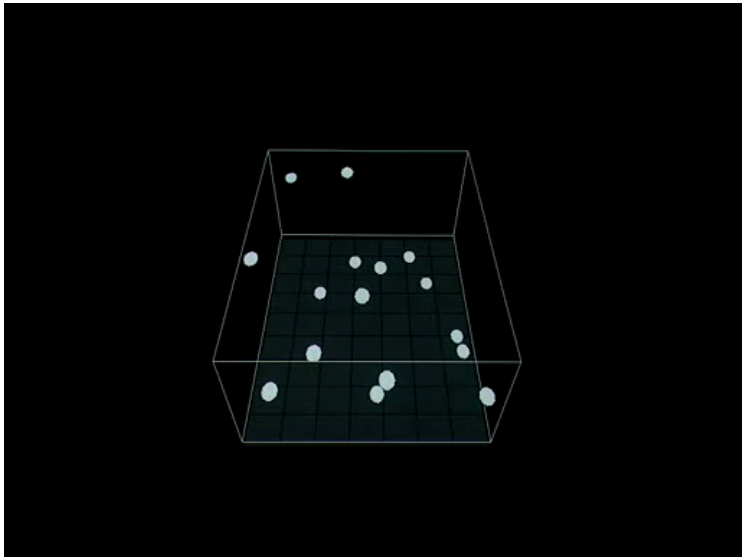


For example, this multiple object tracking task demonstrates one use of FINSTs, individuation



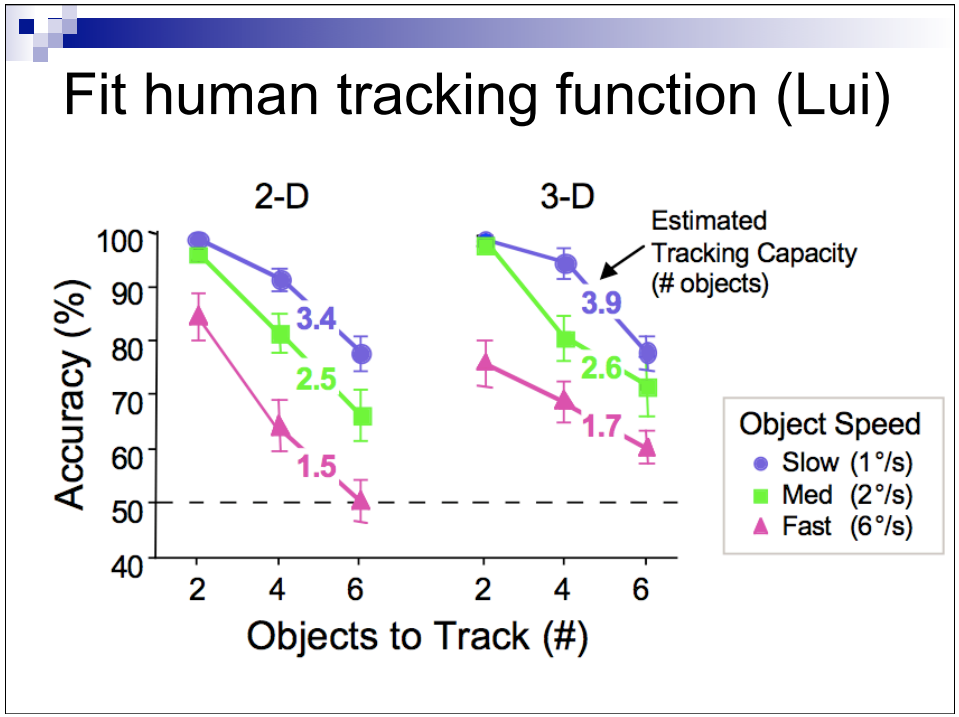
Here is the tracking task in a fishtank VR 3-D projected display

Test performance at different speeds...



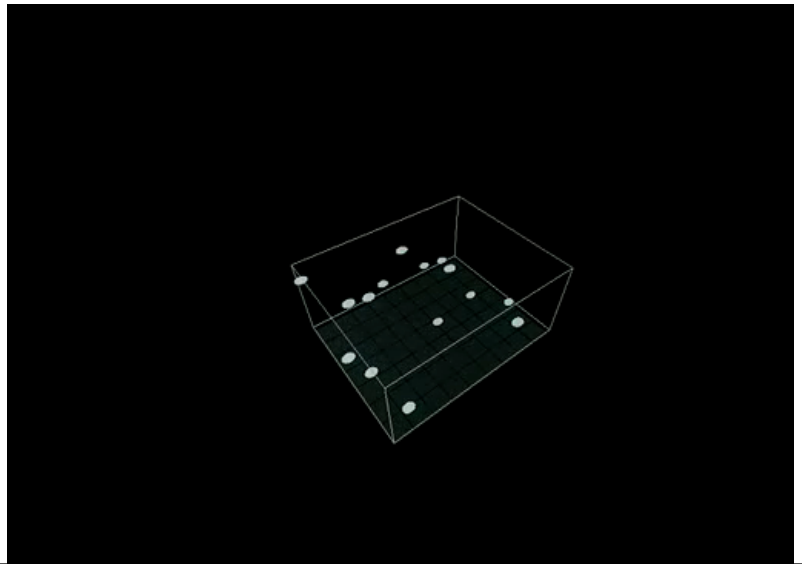
In the case of ATC, one problem with the display transformations might be that they would exceed the ability of observers to maintain a FINST on a given aircraft, thus misindexing its characteristics (such as the fact it is low on fuel) with a different display token.

Note that this tests one aspect of the task, decomposed with reference to the cognitive architecture of human perception in a display environment-- It is not something that would be likely to attract the attention of psychology, since these stimuli are neither ecologically valid nor particularly likely to speak to basic perception

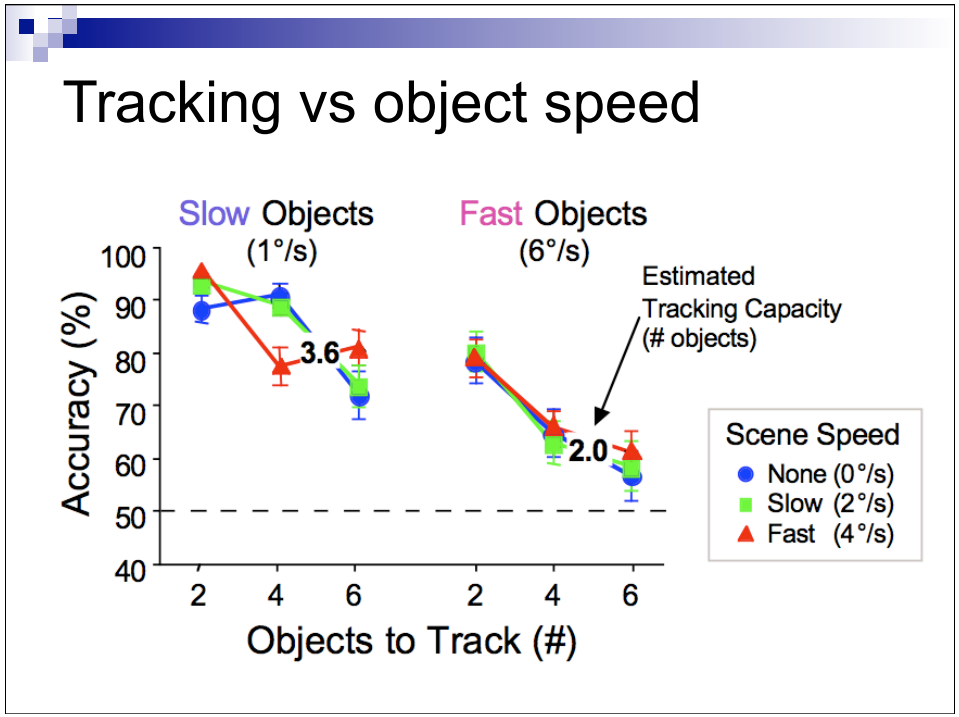


This is normal tracking behaviour, collapsed across subjects. Note the speed/object falloff This study was conducted by a UBC grad student working on the Strategic grant with Jim Enns, John Dill, Kelly Booth, Ron Rensink and myself.

... Then add display motion

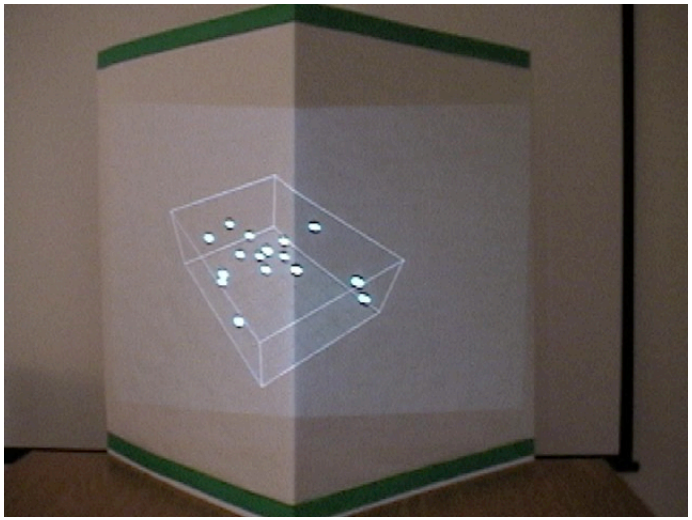


Now we add display transformations. A psychological model would predict that retinal speed function from the previous study would determine performance.

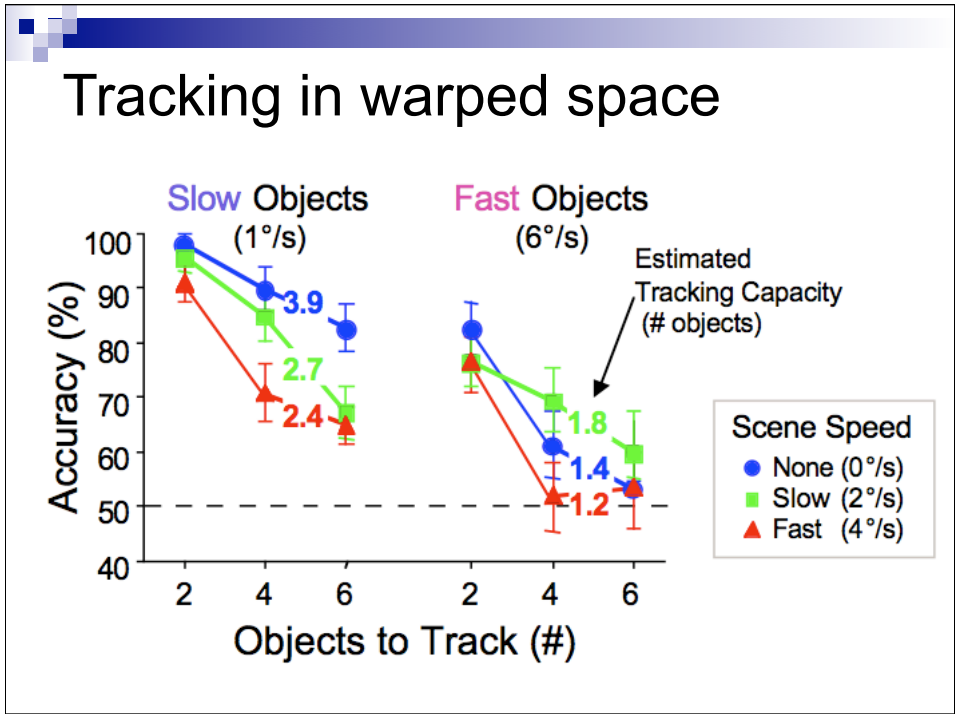


What we found was quite surprising, the retinal speed did not predict tracking-- relative speed within the space did, regardless of the overall motion-- thus performance is allocentric as opposed to egocentric.

Tracking in warped space



What if we perturb the metric characteristics of space? This should adversely affect allocentric tracking



As it does, now we recover the earlier retinal tracking effect.

Conclusion: Humans track in allocentric space

- Retinal speed of targets does not determine performance
- Motion of targets relative to each other does
- But only if motion preserves good metric characteristics of space
- Explanation is at the level of a human - display cognitive system

Other interaction science projects

- Location/categorization of bimodal events
  - Fuzzy Logic model of perception
- Gesture and voice interaction in large-field display environments
  - 2 visual systems model (Trevarthan, Goodale)
- Depth judgments in 3D stereo (“VR”) displays
  - Psychophysical methods (Fechner)

General findings

- Human abilities can scale to novel perceptual situations...
  - “Natural-born cyborgs” (Andy Clark)
- ... but individual differences are large
  - Nature vs nurture? (training or selection?)
  - Model individual performance

Subject data for pointing study

- *Independent factor: Frame position (3 levels)*
- *Dependent factor: Subject response (continuous, x-coordinate)*
  - One for each subject, one for each response condition (classic analysis)

Subject Number	Cognitive Report (Vocal Interaction)	Open Loop Pointing (No Feedback)	Closed Loop Pointing (Lag-Free Feedback)	Closed Loop Pointing (Lagged Feedback)
1	**YES (p < 0.001)**	NO (p = 0.707)	**YES (p < 0.001)**	NO (p = 0.951)
2	**YES (p < 0.001)**	NO (p = 0.985)	NO (p = 0.484)	NO (p = 0.843)
3	**YES (p < 0.001)**	NO (p = 0.975)	**YES (p < 0.001)**	NO (p = 0.952)
4	**YES (p < 0.001)**	NO (p = 0.950)	NO (p = 0.955)	NO (p = 0.697)
5	NO (p = 0.765)	NO (p = 0.968)	NO (p = 0.636)	NO (p = 0.988)
6	**YES (p < 0.001)**	NO (p = 0.572)	**YES (p = 0.034)**	NO (p = 0.752)
7	NO (p = 0.537)	NO (p = 0.800)	NO (p = 0.093)	NO (p = 0.939)
8	**YES (p < 0.001)**	NO (p = 0.963)	NO (p = 0.789)	NO (p = 0.846)
9	**YES (p < 0.001)**	NO (p = 0.933)	**YES (p = 0.012)**	NO (p = 0.358)
10	**YES (p < 0.001)**	NO (p = 0.428)	**YES (p = 0.027)**	NO (p = 0.834)
11	NO (p = 0.285)	NO (p = 0.932)	**YES (p = 0.006)**	NO (p = 0.675)
12	NO (p = 0.899)	NO (p = 0.964)	NO (p = 0.856)	NO (p = 0.940)
13	**YES (p = 0.049)**	NO (p = 0.954)	NO (p = 0.451)	NO (p = 0.971)

Personalization

- Personal Equation: Individual differences in perceptual, indexical attentive, and cognitive processes
  - Test users
  - Model data
  - Describe individual differences in model parameters
- Customize display for PEI
- Attentive systems adapt PEI
  - Within a session: fatigue, attentiveness
  - Between sessions: aging changes

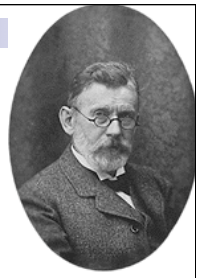
Impact on design

- Design guidelines
- Evaluation methods
- Training regimens for observers
- Customization for individuals

New problem-- how can we incorporate this into design practice? How do we train science-sensitive designers?

Fruit of the tree?
Solve for individuals

Interaction science & design



- Paul Ehrlich
  - Knew chemistry, but not biochem
  - Used science to reduce design space to 900
  - Had animal model for testing
  - Number 606 = Salvarsan
  - Advance science and treatment
- Today
  - Medical science is distributed cognition
  - Clinicians, physiologists biochem...

US Research Efforts

- National Visualization & Analytics Center (NVAC)
  - Battelle/PNNL (Lead, funded by DHS)
  - R&D Agenda panel
    - University: Brown, GMU, Georgia Tech, OSU, Penn State, Purdue, SFU (Dill), Stanford, UC, UI, UM, UNC, UU, WPI
    - Industry: Boeing, Microsoft, PARC, Scandia Labs
    - Gov: CIA, DHS, FBI, NIST, NSA, unspecified
    - Countries: USA(~16), Canada(2), England(1), New Zealand (1)

-The US research effort split among variety of agencies and programs-- NVAC, ARIVA, NSF
-NVAC coordinates VA R&D via a 4th pillar organization, Battelle Institute, a not for profit R&D institute and incubator for technology companies
-Began w high level panel of experts
-private notforprofit co. has indep to bridge silos in gov, & w industry & univs
-can act as single point of entry to US to coord of int'l collab on safety & security
-Consortium coordinates efforts of industry, government, and academics, builds standards etc.
-We: working w NVAC early on, John was on Panel and is the first NVAC Scholar, Both of us have contributed to their National R&D Agenda in VA that is driving US funding

VA for Safety and Security

- New NSERC Strategic project
  - Perceptual cognition stream
  - Spatial cognition stream
  - New social cognition stream
- Quantitative prediction needed
  - Wavelets, Kalman, non-parametric regression, Bayes, etc.
  - need rich data-- Biopotentials, eye movements
- Software for interaction science research

Newell's "You can't play 20 questions with nature and expect to win"
Simon's "sciences of the artificial"
Vicente's "the earth is spherical, $p < .05$"
need Models

Spatial Cognition in complex environments

- Multiple events at different locations
- Multimodal events (sight, sound, touch)
- Action in space
- Tools
  - FINSTs and indexical cognition
  - Space Constancy
    - Functional space constancy: Ability to interact directly
    - Apparent space constancy: Ability to make judgments
  - Sensory integration (FLMP, calibration by pairing)

Communicative Pragmatics & Groupware

- Psycholinguistic pragmatics theories and methods extended to interactive environments
- Support for familiar F2F metachannels
  - Embodied communication (gesture, facial expression, body language
  - Prosody
- Interaction methods to support underlying processes
  - Acknowledgement and repair mechanisms
  - Advancement
  - Layering

Mapping to Visual analytics

- Build toolset: “Thick Description” + Math models
- Understand “gold standard” for interaction
  - Technology to support expertise - “virtuosity”
  - How information from multiple senses is integrated
  - “Tight loop” Perception/action patterns, sequences, rhythms
  - Development of coordination between users

Affording virtuosity

Acknowledgements

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  - Alexander Stevenson
  - Colin Swindels

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– Barry Po

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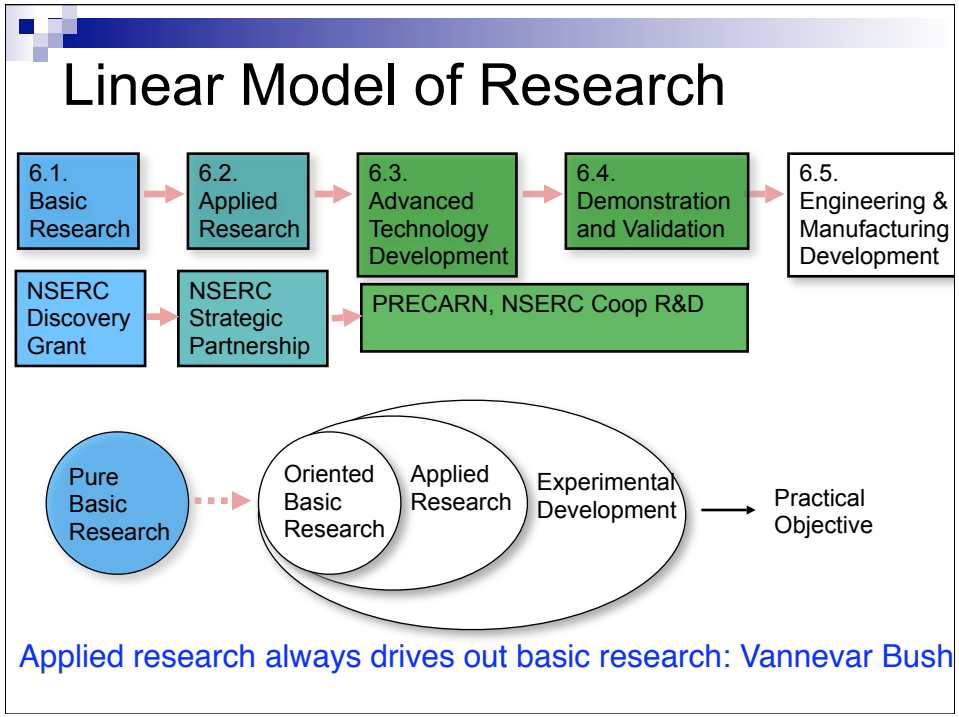
– Boeing
– GM
– HRL
– NSERC
– IRIS
– MAGIC Endowment Fund

Personal equation

- This phrase, which is commonly used in any connection, was first applied to the errors detected in the astronomical observations of a Greenwich observer named Kinnebrook in 1795. The recognized fact that the greater or less inaccuracy is habitual to individual observers has been investigated, e.g. by Bessel (Abhandlungen, jii. 300) and by Wundt (Physiol. Psychol.), and machines have been devised which make allowance for the error caused by the personal equation.

Defining an“Interaction Science”

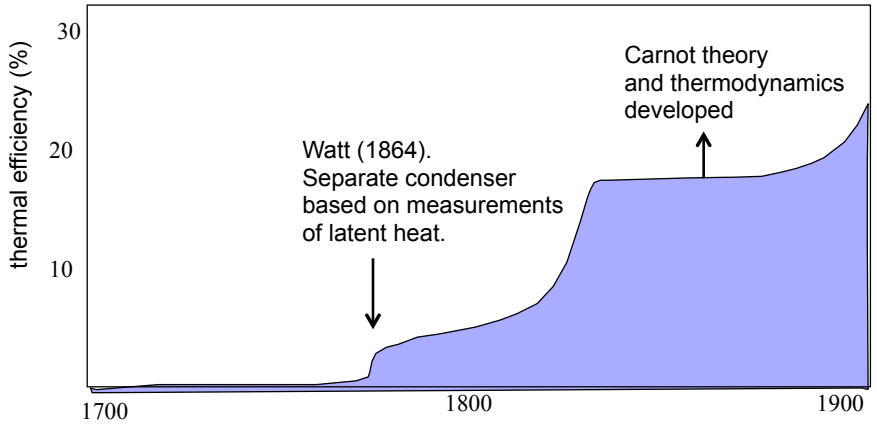
- High need for Cogsci theory base for Visual Analytics
  - Cogsci theories evocative for Visual Analytics
    - Enactive Cog: Perception-Cognition-Action loops
    - Distributed Cog: Problem-solving in joint activities
- Level of description is too high-- how to use?
- Interaction science should ground theory in use
  - Cognitive Architecture task decomposition
  - Toy-world studies, CogArch tests
    - e.g.: Fishtank air traffic control & FINSTS
  - Combine observation & computer models



All this is reflected in the waterfall model of knowledge, where basic science is isolated from use.
From the designers/HCI partitioners viewpoint there is one problem-- the scientists don't work for us.
This was intentional-- Vannevar Bush "Applied research always drives out basic research"

Technology can progress without science

- **steam engine**



Slide from presentation by Stu Card

Other work

- Combine qualitative and mathematical techniques
- Highly skilled interaction
- Study control and communication

Grounded theory

- Open coding
  - Themes arise from the data, phenomena are observed
- Axial coding
  - Relations are drawn between themes and observations in the data
- Triangulation
  - Mixed methods to test theories

Contrast grounded theory with traditional music theory

Objectivist vs constructivist

Grounded theory follows a set of assumptions about the nature of knowledge. It assumes that in order for a theory to be meaningful, it must be drawn from real world data.

Add HCI aspects/analyses

- Replace flutes with analog synth
- Allows us to capture
  - Control: Breath and fingering
  - Communication: Gestural motion
- Can add HCI variables such as lag, bias, noise etc. to understand how skilled performers compensate
- May feedback to music controller design

Low level observation based on higher level goals. What we see here is the beginnings of the kind of mature cross disciplinary collaboration that characterizes bio-medical research and is elsewhere absent.

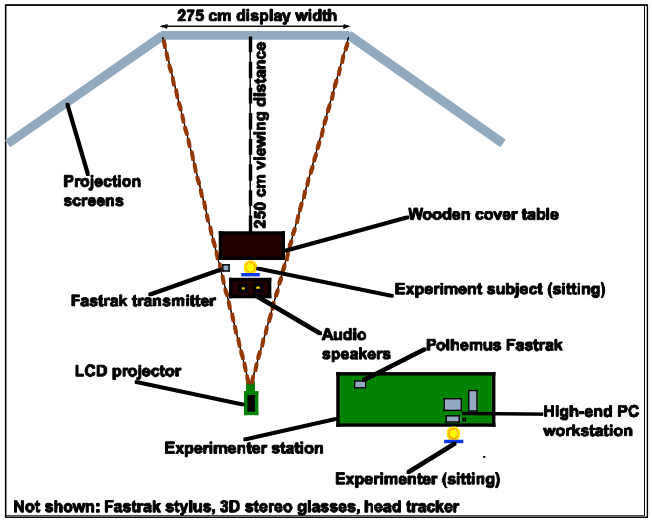
Some 2 visual system illusions

stimuli	deficits	spared abilities
Tichner circles	Size report	Grip scaling
Target displacement during saccade	Detection of displacement, location report	Pointing
Moving or off-centre frame	Induced motion, location report	Pointing
Sound with displaced visual distractor	Pointing	Apparent location of sound

Applying 2 visual systems to VR

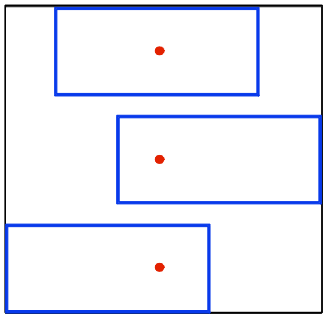
- Graphical content vs. world
  - Object and scene onsets (cuts) common
  - Point of view pans, zooms etc.
  - Conflict between multimodal cues common
    - Conflict between acceleration and vision
    - Conflict between synthetic cues (e.g. depth)
- Does immersion magnify these effects?
- Do they differ between the 2 visual systems?

Apparatus


275 cm display width
250 cm viewing distance
Projection screens
Wooden cover table
Fastrak transmitter
Experiment subject (sitting)
Audio speakers
Polhemus Fastrak
LCD projector
High-end PC workstation
Experimenter station
Experimenter (sitting)
Not shown: Fastrak stylus, 3D stereo glasses, head tracker

2VS & interaction in the large

- Task: Localize target with voice (far left, near left centre etc.) or pointing
- Induced Roeloffs Effect: displaced frame should cause ventral system errors (ASC), but not dorsal (FSC)



Experimental protocol

- Display appears, then disappears
- Verbal report & pointing tasks
  - 1 block of verbal report
  - 1 block pointing with no visual feedback
  - 1 block pointing with visible pointer
  - 1 block pointing with 1/2 second lagged pointer
- Within subject psychophysical analysis
- Meta-analysis of proportion of subjects exhibiting effects

Findings

1. Can you tell if a target is on the left or right?
   - 3 out of 7 males, 7 out of 7 females made errors
2. Can you point to it without seeing your hand?
   - 6 out of 10 who failed #1 were correct
3. Are you better with a (simulated) laser pointer?
   - Out of 6 who point accurately in 2, all fail
4. Will pointing accuracy be affected if visible pointer lags pointing?
   - 3 of the 6 who failed #3 succeed

Results

- Displaced frame leads to verbal errors (ASC)
- Most subjects who made verbal errors did not make pointing errors (FSC) w/o cursor.
- Visual feedback hurts (FSC -> ASC)
- Time lagged feedback (>FSC) helps
- Fits predictions of 2 visual systems theory:
  - Pointing (dorsal) more robust against illusion
  - Feedback shifts to ventral, increases illusion

Less information = better performance