Cognitive Modeling, Cognitive Engineering, & Human Error

Acknowledgments
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Newell's 20 Questions Article

- Cognitive psychology has reached a point (35 years ago) where continuing to amass a catalogue of phenomena ceases to be very helpful – what we need is a grand theory of cognition.

20 Questions

- What are the main problems Newell identified with psychological research at the time?

PHENOMENA

1. Physical - name match difference (Posner)
2. Continuous rotation effect (Shepard)
3. Subitizing (Klahr)
4. Chess position perception (DeGroot)
5. Chunks in STM (Miller)
6. Recency effect in free recall (Murdock)
7. Instructions to forget (Bjork)
8. PI release (Wickens)
9. Linear search in sets in STM (Sternberg)
10. Non-improvement of STM search on success (Sternberg)
11. Linear search on displays (Neisser)
12. Non-difference of single and multiple targets in display search (Neisser)
13. Rapid STM loss with interpolated task (Peterson and Peterson)
14. Acoustic confusions in STM (Conrad)
15. High recognition rates for large set of pictures (Teghtsoonian and Shepard)
16. Visual icon (Sperling)
17. LTM hierarchy (Collins and Quillian)
18. LTM principle of economy (Collins and Quillian)
19. Successive versus paired recall in dichotic listening (Broadbent)
20. Click shift in linguistic expressions (Ladefoged and Broadbent)
21. Consistent extra delay for negation (Wason)
22. Saturation effect on constrained free recall (?)
23. Conservative probabilitistic behavior (Edwards)
24. Clustering in free recall (Bousefield)
25. Constant recall per category in free recall (Tulving)
26. Serial position effect in free recall (?)
27. Backward associations (Ebenholtz and Asch)
28. Einstellung (Luchins)
29. Functional fixity (Dunker)
30. Two-state concept models (all or none learning) (Bower and Trabasso)

Fig. 1. A partial list of psychological phenomena and investigators (parentheses).

PHENOMENA (cont'd)

31. Concept difficulty ordering: conjunct, disjunct, cond, ... (Hovland)
32. Reversal learning (Kendlers)
33. von Restorff effect
34. Log dependency in disjunctive RT
35. Forward masking
36. Backward masking
37. Correlation between RT and EEG
38. Moon illusion (Boring)
39. Perceptual illusions (Mueller-Lyer, etc.)
40. Ambiguous figures (Necker cube)
41. Cyclopean perception (Julesz)
42. Imagery and recall (Pavio)
43. Constant time learning (Murdock, Bugelski)
44. Probability matching (Humphreys)
45. Transmission capacity in bits (Quastler)
46. Pupillary response to interest (Hess)
47. Stabilized images (Ditchburn)
48. Meaningful decay of the stabilized image (Hebb)
49. Categorical concepts (phonemes) (Lieberman)
50. Effect of marking (Clark)
51. Negative effect in part-whole free recall learning (Tulving)
52. Storage of semantic content over linguistic expression (Bransford)
53. Information addition (Anderson)
54. Induced chunking (Neal Johnson, Gregg and McLean)
55. Rehearsal
56. Repetitive eye scanning (Noton and Stark)
57. Positive effects of redundancy on learning (syntactic, semantic)
58. Effects of sentence transformations on recall (Miller)
59. Effect of irrelevant dimensions in concept learning (Restle)

Fig. 1 (continued).

BINARY OPPOSITIONS

1. Nature versus nurture
2. Peripheral versus central
3. Continuous versus all-or-none learning
4. Uniprocess versus duoprocess learning (Harlow)
5. Single memory versus dual memory (STM-LTM) (Melton)
6. Massed versus distributed practice
7. Serial versus parallel processing
8. Exhaustive versus self-terminating search
9. Spatial logic versus deep structure
10. Analog versus digital
11. Single code versus multiple codes
12. Contextual versus independent interpretation
13. Trace decay versus interference forgetting
14. Stages versus continuous development
15. Innate versus learned grammars (Chomsky)
16. Existence versus non-existence of latent learning
17. Existence versus non-existence of subliminal perception
18. Grammars versus associations for language (reality of grammar)
19. Conscious versus unconscious
20. Channels versus categorizing in auditory perception (Broadbent)
21. Features versus templates
22. Motor versus pure perception in perceptual learning
23. Learning on non-error trials versus learning only on error trials
24. Preattentive versus attentive

Fig. 2. A partial list of binary oppositions in psychology.

Diagnosis

- There is no framework in psychology
  - alternate explanations crop up ad nauseam for each phenomenon without leading to a grand theory of human cognition
- "…the 'normal' means of science may not suffice."
  - What did he mean by that?
    - Hint: What was the "slippery eel" problem Newell identified?

Potential Remedies

- "…the 'normal' means of science may not suffice."
  - What did he mean by that?
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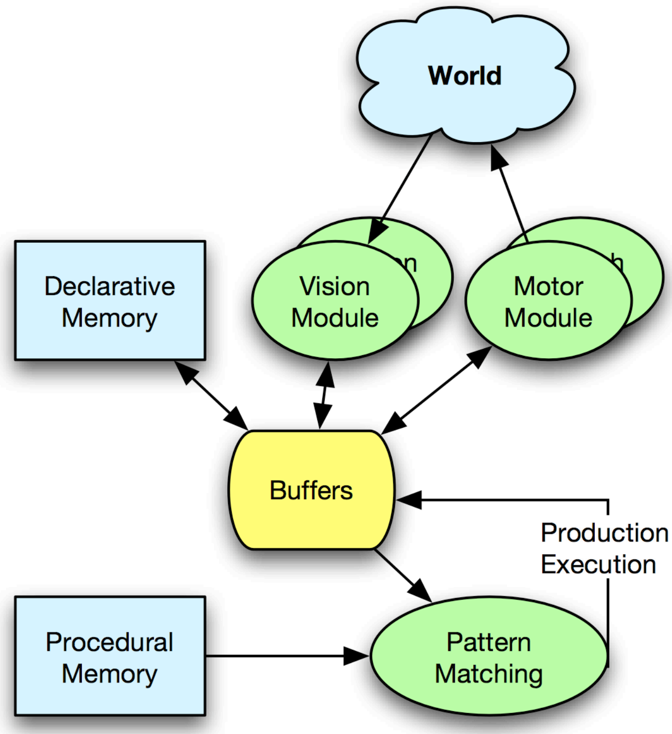
One Potential Remedy: The Cognitive Architecture

- Embodies the invariant human cognitive resources and constraints
  - Used to construct models of human task performance

ACT-R

- Inputs:
  - Knowledge
    - IF-THEN rules (termed “productions”)
    - Declarative knowledge (“chunks”)
    - Subsymbolic parameters
  - Simulated task environment/world
- Output: Time-stamped behavior sequence



ACT-R Example

- Let's say you have a large environment with many devices controlling distal equipment
  - Like, say, a Navy ship
- You want to reduce crew requirements
  - Meaning more distal control
- New functionality must be added, new procedures learned by the operators
  - That is, things change
- How do we design human-machine interfaces and procedures to minimize the risk of error and slowdown?
  - In even the routine procedures

ACT-R Example

- To understand this, we need to know how people mentally represent routine procedures
  - Perform experiments to identify factors relevant to human performance
    - How do people represent the routine tasks that they preform?
    - How do people represent the space in which they perform those tasks?

CAT Triad

- Human performance not resultant from any one thing, but from interaction of three:
  - Cognition
  - Artifact
  - Task

ACT-R Example

- We can build models that embody the collection of human performance phenomena for a given task
  - Architecture: what’s invariant about human cognition
  - Model: what’s specific to the human and the task
  - CAT Triad: running the model allows interactions to play out

Engineering Models of Human Performance

- A priori quantitative predictions of human performance
- Learnable and usable by system designers
- Cover total tasks
- Usefully approximate

Card, Moran, & Newell

- The computer is man's most important tool
  - But at the time, principles governing its design was poorly understood
- Use of the computer differs fundamentally from other tools
- An applied psychological science needs:
  - Task Analysis
  - Calculation
  - Approximation

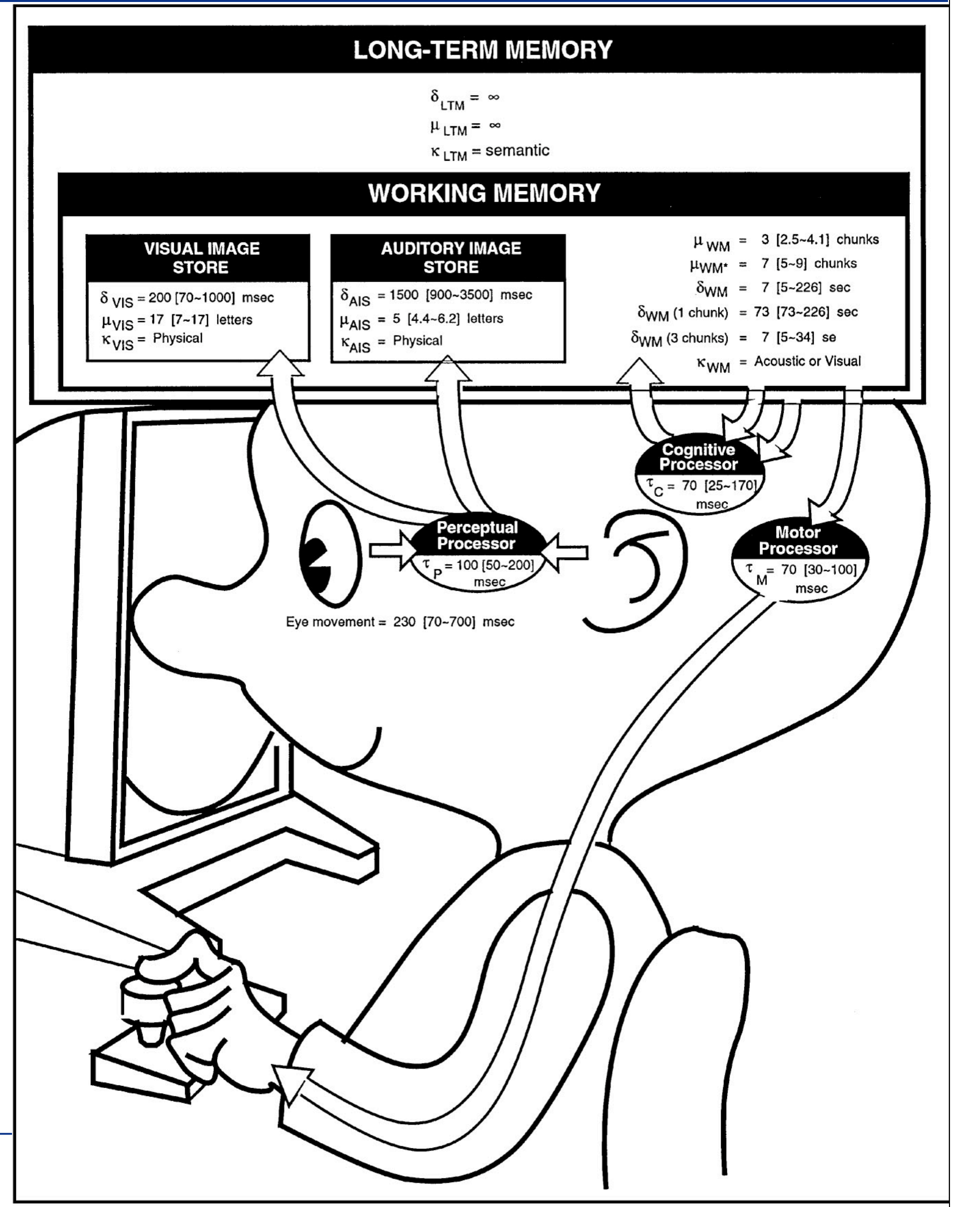
GOMS

- A Framework for Cognitive Engineering
  - Based on Model Human Processor
- Goals: the objective of the task and sub-tasks
- Methods: well-learned sequences of subgoals and low-level actions that can accomplish a goal
- Operators: low-level actions
- Selection Rules: if more than one method applies, specifies when each should be used

The Model Human Processor

- Three processors
- Associated memories
- Parameters
- Principles of Operation

- Quantitative predictions could be made for simple tasks, e.g.,
  - Speed of animation to create illusion of movement
  - Position of function keys for most efficient performance
  - And many more…



A Simple Example

- How can we predict pointing?
  - e.g., in a GUI
- Fitts' Law
  - T = average movement time
  - a = start/stop time of the device
  - b = speed of the device
  - D = distance to target
  - W = width of the target

$$T = a + b\log_2\left(\frac{D}{W} + 1\right)$$

Another Simple Example

- Given n equiprobable choices, how long will it take the user to pick one?
- Hick-Hyman Law
  - $T = b \cdot \log_2(n + 1)$
    - b = empirically-determined constant
    - + 1 because there is uncertainty about whether to respond at all, in addition to which response to make

Human Error

- Powerful technologies can have catastrophic consequences
- “Be more careful” admonishments don’t work
- Systems engineering approach

Roots

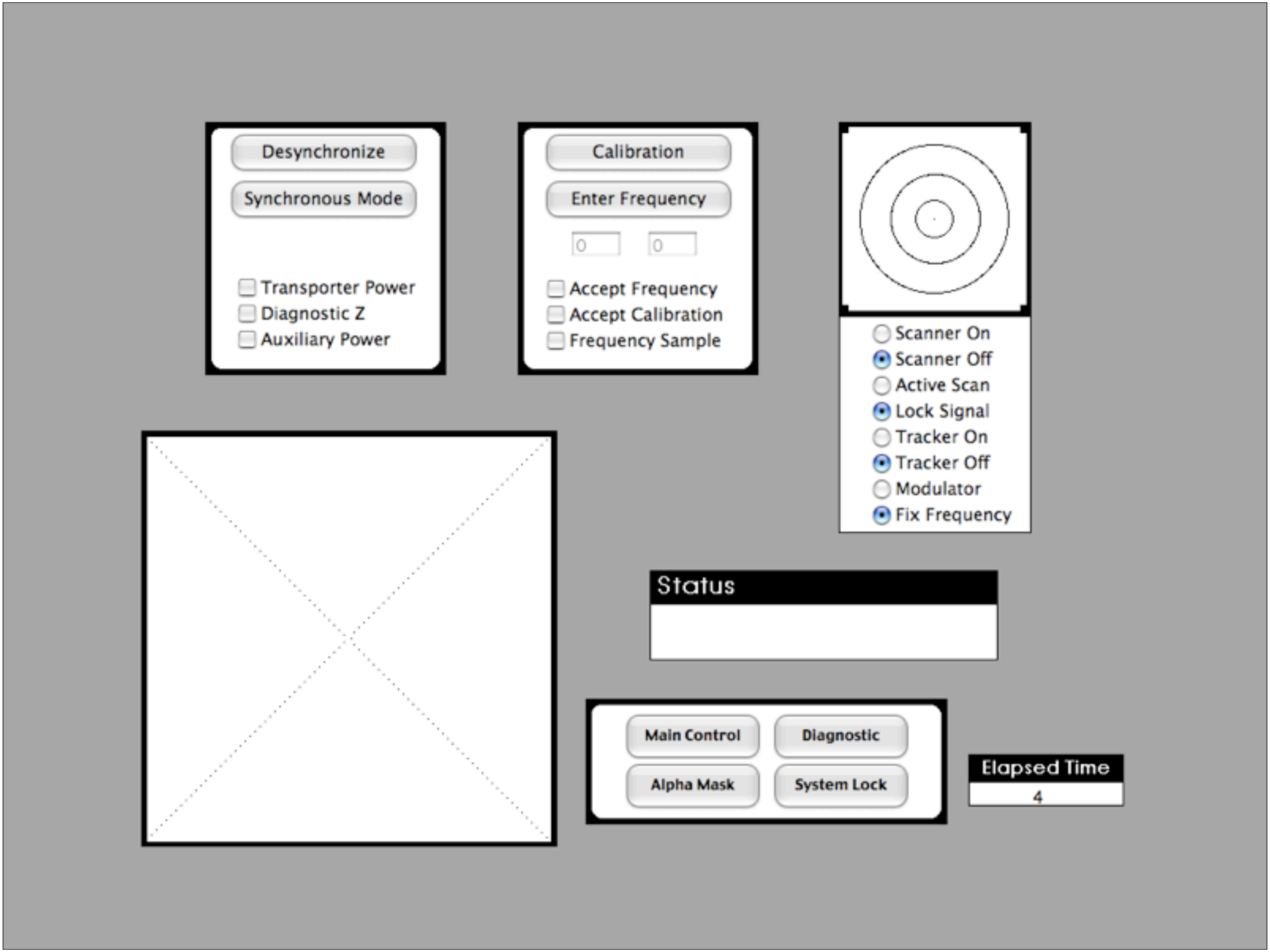
- WWII: Highly trained pilots crashed mechanically-sound aircraft
  - Big problem
    - Loss of valuable personnel
    - Loss of valuable machines

Roots

- Aircraft disasters really bad for commercial aviation
- Airlines developed safety culture
  - Check lists
  - Crew Resource Management (CRM)
  - “Sterile Cockpit Rule”
- Aviation’s approaches to safety have largely been successful
  - Now other industries are adopting their practices
    - E.G., CRM in the operating room

Human Error

- Human Limitations
- The “Cognitive Balance Sheet”
  - Errors often result because attributes of useful cognitive functions can have their drawbacks
- Induced Errors
  - E.g., Mode Errors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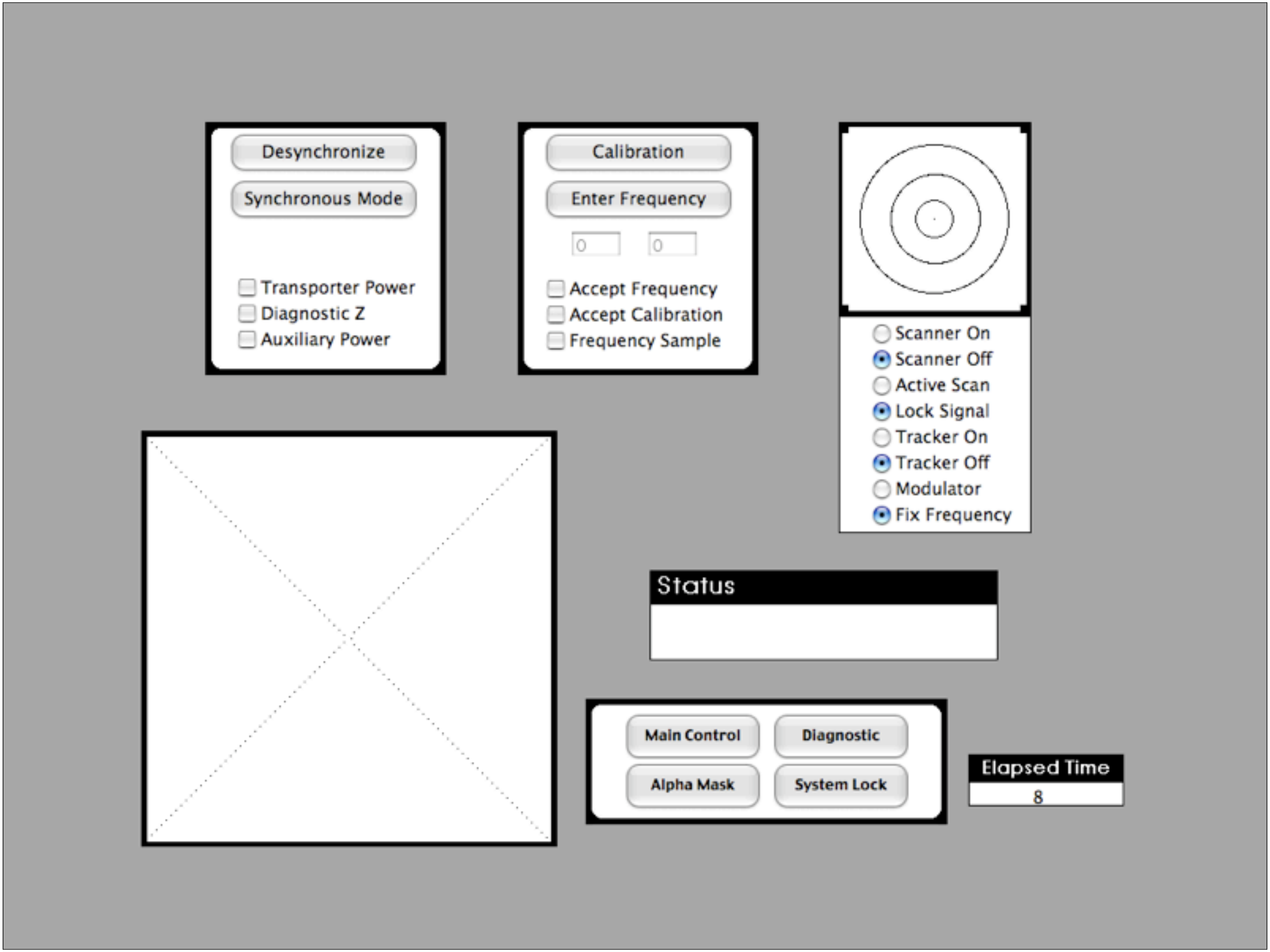
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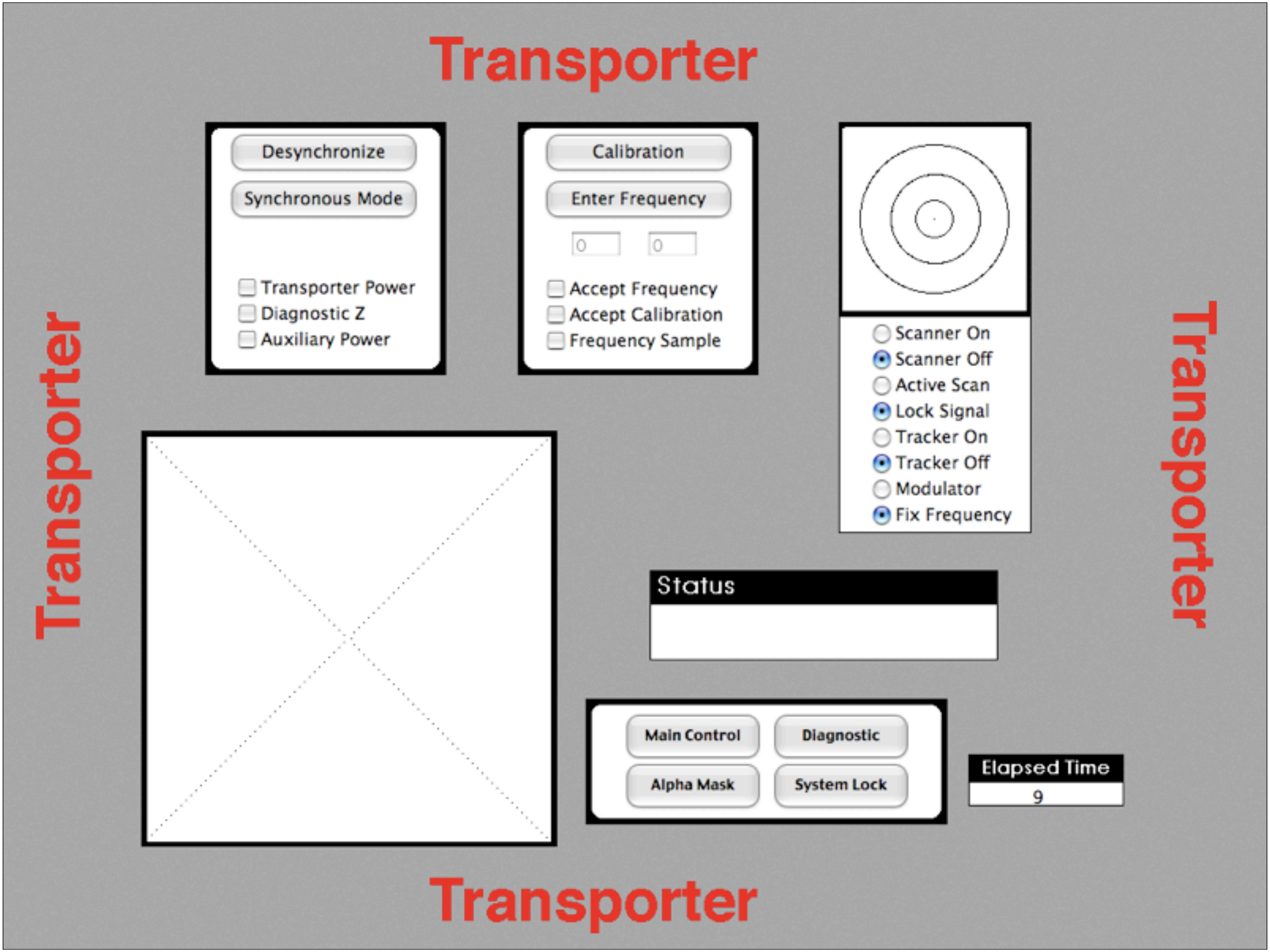
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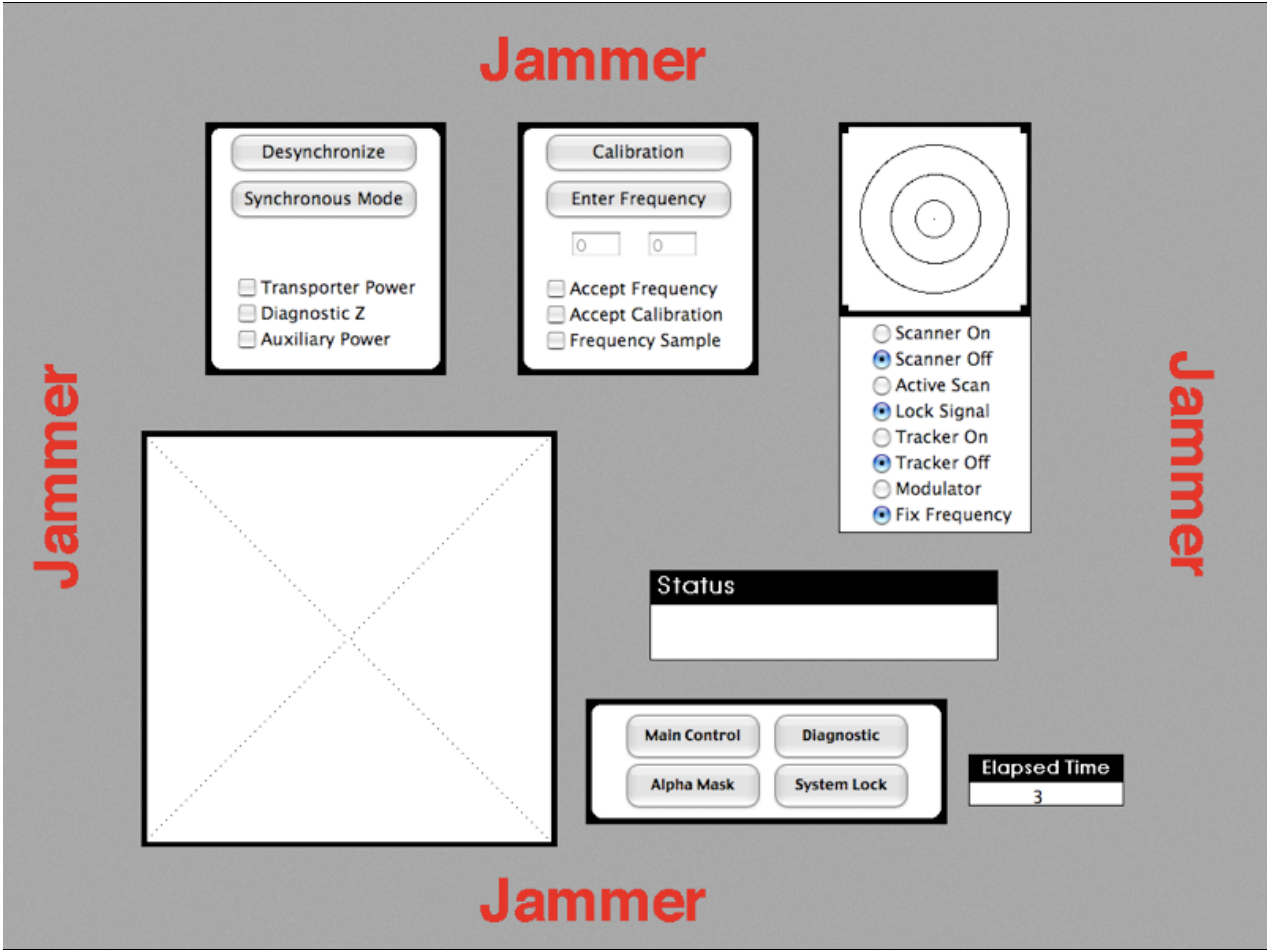
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Environment

- Error often a function of human operator's environment
  - tools/interfaces
  - work groups
  - organizations

Swiss Cheese…

- …model of Human Error
  - organizational (e.g., safety culture)
  - task structure
  - environmental conditions (e.g., weather)
  - artifact design
  - operator actions

Strategies for Combating Error

- Good Design
  - Incorporate good human factors from start to finish
- Crew Resource Management
  - structure work teams & procedures to facilitate communication, situation awareness, decision-making
- Automation
  - Take hard tasks away from the human
- Organizational Approaches
  - “Sterile Cockpit Rule”
  - Rules governing shift workers
  - Equipment purchasing