Module IN 2111

3D User Interfaces
- Dreidimensionale Nutzerschnittstellen -

Prof. Gudrun Klinker

Evaluation of User Interfaces
SS 2023

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Literature

Related Work:

- Ben Shneiderman and Catherine Plaisant: *Designing the User Interface, Strategies for Effective Human-Computer Interaction*, 4th edition, Addison Wesley, 2005, (http://wps.aw.com/aw_shneider_dtui_4).
- D. Bowman, E. Kruijff, J. LaViola Jr., I. Poupyrev: *3D User Interfaces, Theory and Practice*, Addison Wesley, 2004.
- J. Bortz: Statistik für Human- und Sozialwissenschaftler, 6. Auflage, Springer, 2004.
- J. McClave, F. Dietrich II: Statistics, Dellen Publishing Company, 1985.
- J.E. Swan II, S.R. Ellis, B.D. Adelstein, Conducting Human-Subject Experiments with Virtual and Augmented Reality, VR 2007 Tutorial, (http://www.cse.msstate.edu/~swan/teaching/tutorials/Swan-VR2007-Tutorial.pdf).

Agenda

1. Introduction
2. Evaluation Design
3. Usability Testing
4. Statistics Tools

1 Introduction

Purposes of Evaluations

- Definition
  Analysis, assessment, and testing of an artifact
- Iterative approach
  Design – evaluation – redesign – …
- Goals
  - Problem identification
  - Redesign
  - Understanding of usability
    (to obtain design guidelines)
  - Development of performance models
    (to predict user performance)

1 Introduction

Terminology

- *Usability*
  Encompasses everything about an artifact and everything that affects the person‘s use of the artifact
- *Evaluation*
  Measures some aspects of the usability of an interface:
  - System performance, task performance, user preference

Agenda

1. Introduction
2. Evaluation Design
3. Usability Testing
4. Statistics Tools

2. Evaluation Design

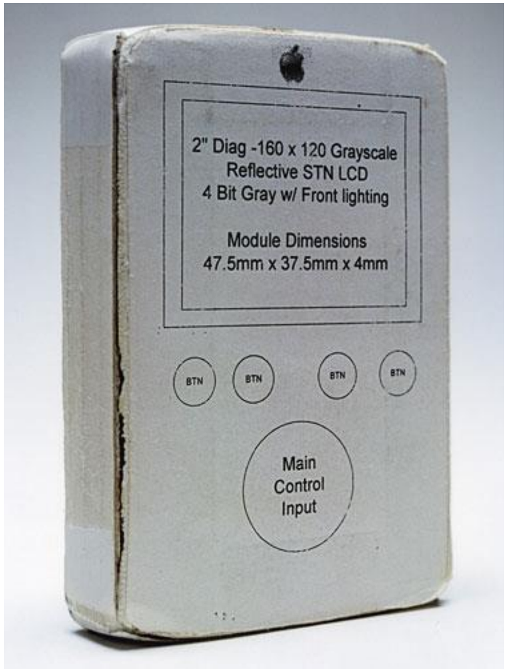
2.1 Planning an Evaluation

- User task analysis
  - Generate lists of detailed task descriptions, sequences, relationships, user work information flow
- Representative scenarios
  - Must be accurate and complete
  - More than simple atomic, mechanical or physical-level tasks
  - Should include high-level, cognitive, problem-solving tasks

2.1 Planning an Evaluation

- Prototyping
  - Paper-based sketch
  - Storyboard
  - Static mockup

  - Wizard of Oz (WOZ) technique:
    Human as a substitute for missing functionality
    (e.g. speech recognition)



Apple via Wired Magazine

2. Evaluation Design

2.1 Planning an evaluation

→ 2.2 Evaluation approaches

2.3 Evaluation metrics

2.2 Evaluation Approaches

Phases and Strategies

- P1: before development
  - Expert reviews
  - User surveys
- P2: during development
  - Usability testing and laboratories
  - User surveys
- P3: after development
  - Acceptance tests
  - Evaluation during active use
  - User surveys

Methods

- Phase 1
  - Cognitive walkthrough
  - Heuristic evaluation
- Phase 2
  - Formative evaluation
  - Summative evaluation
  - Questionnaires
  - Interviews and demos
- Phase 3
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2.2.1 Phase 1: Before Development

Expert Reviews

- Half day to one week effort
  - A lengthy training period may sometimes be required to explain the task domain or operational procedures.
- Can be scheduled at several points in the development process
  - When experts are available
  - When the design team is ready for feedback.

2.2.1 Phase 1: Before Development

Expert Reviews

- Different experts tend to find different problems in an interface. 2-3 expert reviewers can be highly productive.
- Danger: Experts may not have an adequate understanding of the task domain or the user communities.
- For successful expert reviews: Choose knowledgeable experts who are familiar with the project situation and who have a longer term relationship with the organization.
- Problem: Even experienced expert reviewers know little about how typical users, especially first-time users will really behave.

2.2.1 Phase 1: Before Development

Cognitive Walkthrough

- Step through common tasks that a user would perform
- Evaluate the interface‘s ability to support each step

2.2.1 Phase 1: Before Development

Heuristic Evaluation

Guidelines-based expert evaluation

- Experts apply a set of heuristics or design guidelines
- NO representative users

2.2 Evaluation Approaches

Phases and Strategies

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2.2.1 Phase 1, 2 and 3

User Surveys

- Familiar, inexpensive and general
  - Complementary to usability tests and expert reviews
- Important:
  - Clear goals in advance
  - Development of focused items that help attain the goals
- Users could be asked for their subjective impressions about specific aspects of the interface.
- ! Many people prefer answering a brief survey displayed on a screen, instead of filling in and returning a printed form !

2.2 Evaluation Approaches

Phases and Strategies

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- Phase 3
  - Interviews and demos

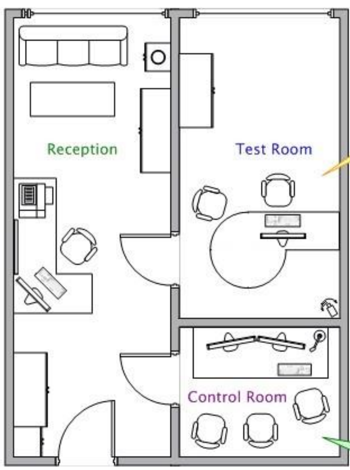
2.2.2 Phase 2: During Development

Usability Testing and Laboratories

- Increasingly important since the early 1980s
- Speed up in many projects plus dramatic cost savings
- Specially constructed usability laboratories
  - Typical setup: two 10 by 10 foot areas, one for the participants to do their work and another, separated by a half-silvered mirror, for the testers and observers (designers, managers, and customers).

2.2.2 Phase 2: During Development

Usability Testing and Laboratories

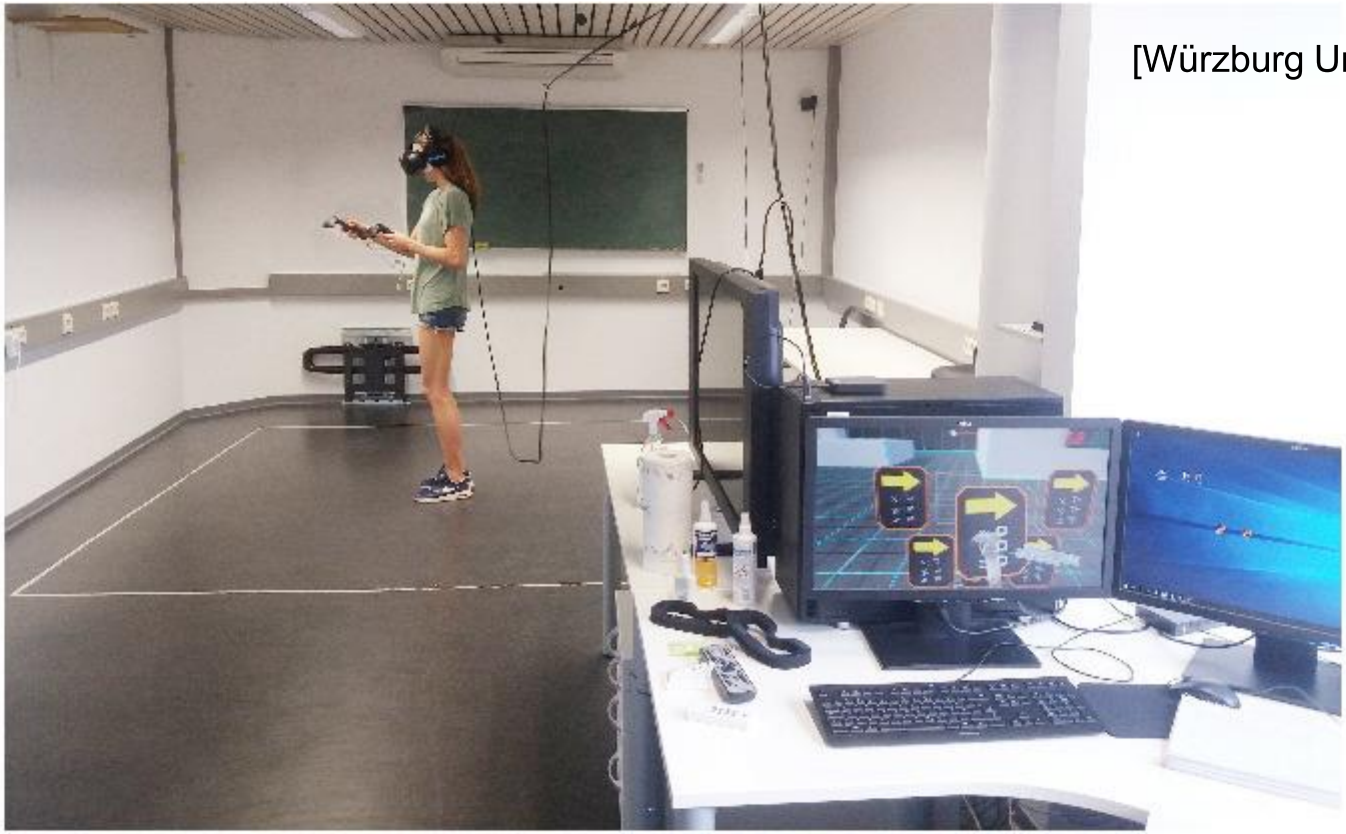


[interUX]

[fio hotJar]

2.2.2 Phase 2: During Development

Usability Testing and Laboratories



[Würzburg University]

2.2.2 Phase 2: During Development

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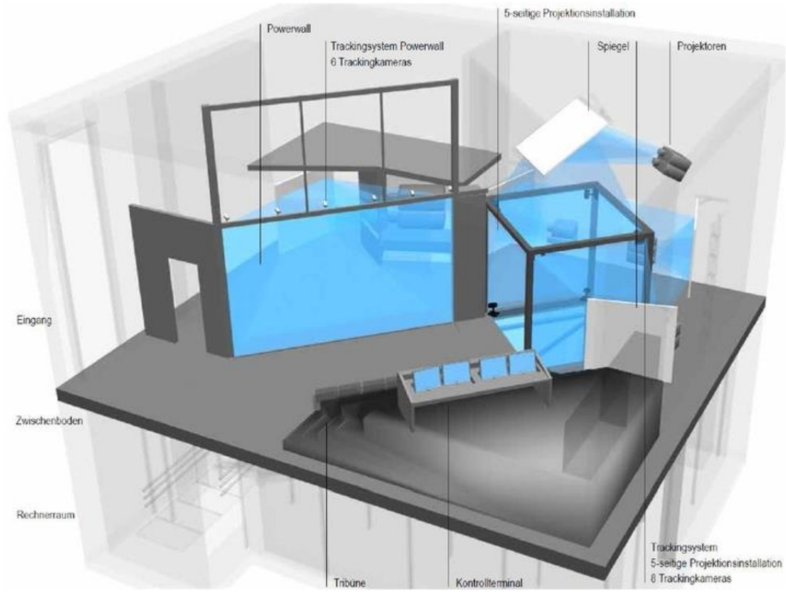


[VR Cave,
Leibniz Supercomputing Centre LRZ]

2.2.2 Phase 2: During Development

Usability Testing and Laboratories

- Participants should represent the intended user communities
  - Background in computing
  - Experience with the task
  - Motivation
  - Education
  - Knowledge of the natural language used in the interface
- Limitations
  - Emphasizes first-time usage
  - Limited coverage of the interface features
- Important
  - Detailed logging/videotaping during user tests

2.2.2 Phase 2: During Development

Formative Evaluation (*„Discount (cheap) usability testing“***)**

- Observational, empirical method
- Applied during evolving stages of design
- Assess user interaction by interactively placing representative users in task-based scenarios
- Goals
  - Identify problems
  - Assess design‘s ability to support user exploration, learning and task performance
- Informal .. Very formal and extensive
  - Qualitative results: critical incidents, user comments, general reactions
  - Quantitative results: task timing, errors

2.2.2 Phase 2: During Development

Summative Evaluation (Competitive usability testing)

- Statistical comparison of two or more configurations of UI designs, UI components, and/or UI techniques
- Representative users perform task scenarios
- Formal or informal

- Generally performed after UI designs are complete
- Factorial experimental design with multiple independent variables
- Helps evaluators compare the productivity and cost benefits associated with different UI designs
- Requires consistent set of task scenarios that compare a design‘s support for specific user task performance

2.2.2 Phase 2: During Development

Questionnaires

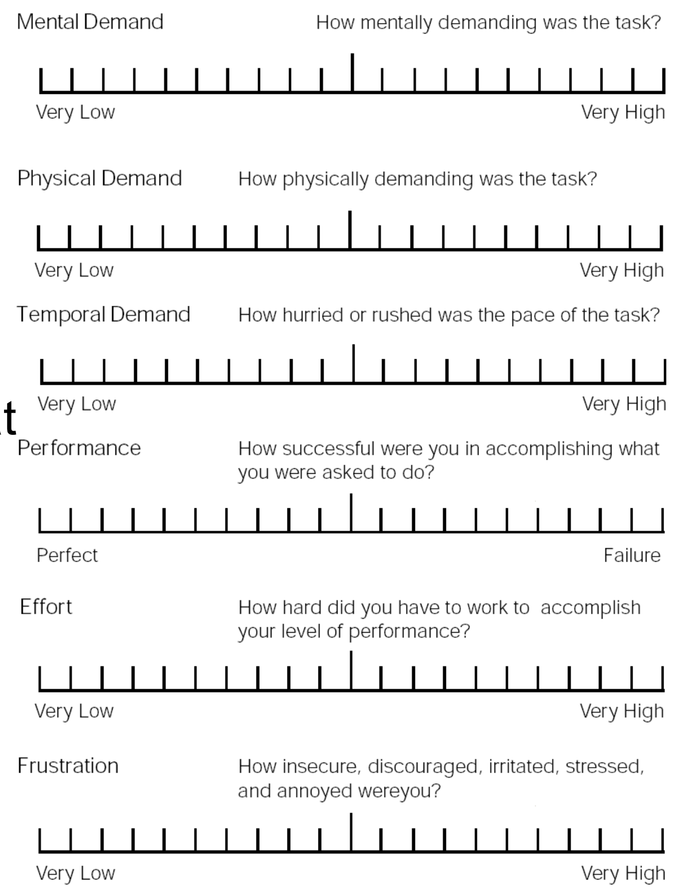
- Written set of questions
- Given to users before, in between or after they have participated in a usability evaluation session
- Demographic information, subjective data
- Examples
  - SUS
  - NASA-TLX

- Used frequently
  - Help to find out about degree of presence, cyber sickness

2.2.2 Phase 2: During Development

Mental workload

- NASA-TLX (Task Load Index)
  - Subjective workload assessment tool
  - For various human-machine systems
  - Multi-dimensional rating procedure
  - Score based on a weighted average of rat
    - Mental Demands
    - Physical Demands
    - Temporal Demands
    - Own Performance
    - Effort
    - Frustration



SG Hart, LE Staveland. **Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research,** Human Mental Workload, 1988
NASA TLX Homepage: http://humansystems.arc.nasa.gov/groups/TLX/

2.2.2 Phase 2: During Development

System Usability Scale (SUS)

- John Brooke, 1986
- Subjective determination of usability (estimation based on 10 questions) to determine:
  - Effectiveness (users can achieve their goals)
  - Efficiency (Little effort is required for the achievement of these goals)
  - Satisfaction (the experience was satisfactory)
- Score in range 0..100 (raw score * 2.5)

	Strongly disagree				Strongly agree
I think that I would like to use this system frequently	○	○	○	○	○
I found the system unnecessarily complex	○	○	○	○	○
I thought the system was easy to use	○	○	○	○	○
I think that I would need the support of a technical person to be able to use this system	○	○	○	○	○
I found the various functions in this system were well integrated	○	○	○	○	○
I thought there was too much inconsistency in this system	○	○	○	○	○
I would imagine that most people would learn to use this system very quickly	○	○	○	○	○
I found the system very cumbersome to use	○	○	○	○	○
I felt very confident using the system	○	○	○	○	○
I needed to learn a lot of things before I could get going with this system	○	○	○	○	○

J Brooke. **System Usability Scale (SUS): A Quick-and-Dirty Method of System Evaluation User Information**, Digital Equipment Co Ltd, Reading, UK, 1986

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2.2.2 Phase 2: During Development

- **Interviews**
  - Oral conversation with users
    - Can gather more information than a questionnaire
    - Useful for getting subjective reactions, opinions, insights about users‘ reasoning
  - Structured interviews
    - Predefined set of questions and responses
  - Open-ended interviews
    - Interviewees can provide additional information
    - Interviewer can ask broad questions
- **Demos**
  - Often shown in conjunction with user interviews

Interviews and demos often used at the end of formative or summative usability evaluations

2.2 Evaluation Approaches

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2.2.3 Phase 3: After Development

Acceptance Tests

- For large implementation projects
  - In large systems: 8-10 such tests should be carried out on different components of the interface and with different user communities.
- Test after product completion
  - Further field testing before national or international distribution
- Goal: Force as much of the evolutionary development as possible into the prerelease phase, when change is relatively easy and inexpensive to accomplish.

2.2.3 Phase 3: After Development

Evaluation during active use

- Interviews and focus group discussions
  - Interviews with individual users to pursue specific issues
  - Group discussions to ascertain the universality of comments
- Continuous user-performance data logging
  - Guidance to system maintainers in optimizing performance and reducing costs for all participants
- Online or telephone consultants
- Online suggestion box or trouble reporting
- Online bulletin board or newsgroup
- User newsletters and conferences

Overview

2. Evaluation Design

2.1 Planning an evaluation

2.2 Evaluation strategies and phases (approaches)

→ 2.3 Evaluation metrics

2.3 Evaluation Metrics

→ 2.3.1 System Performance Metrics

2.3.2 Task Performance Metrics

2.3.3 User Preference Metrics

2.3.1 System Performance Metrics

- Average frame rate
- Average latency
- Network delay
- Optical distortion
- …

- Only important insofar as they affect users‘ experience or task performance

2.3.2 Task Performance Metrics

- Time to navigate to a specific location
- Accuracy of object placement
- Number of errors a user makes in selecting an object from a set
- Speed of learning a concept
- Spatial awareness
- …

- Problem: users cannot optimize simultaneously for both speed and accuracy

2.3.3 User Preference Metrics

- Subjective perception of the interface by the user
  - Perceived ease of use
  - Ease of learning
  - Satisfaction
- Obtained by questionnaires or interviews

2.3.3 User Preference Metrics

- Presence (the „feeling of being there“) (3D UIs)
  - User rating on a given scale
  - Physiological measurements
  - User‘s reactions to events
  - Test of memory for environment and objects
- User comfort
  - Simulator sickness
  - Physical aftereffects of being exposed to 3D systems
  - Subjective measures (rating scales)

Agenda

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3. Usability Testing

→ 3.1 Definition

3.2 Testing process

3.3 Experimental structure

3.1 Definition

Definition

Usability is the measure of the quality of the user experience when interacting with something
– whether a Web site, a traditional software application, or any other device the user can operate in some way or another [J. Nielson].

Ergonomic requirements (DIN ISO EN 9241):

- **Pragmatic quality** (PQ)
  - **Effectiveness** (accuracy, completeness of task performance)
  - **Efficiency** (operating expense, speed)
- **Hedonic quality** (HQ): emotional, satisfactory experience
  - **Satisfaction** (freedom of interference, positive attitude of using a product)

3.2 Testing Process

- Quantitative procedure to test against predefined goals
  e.g.: Initial performance, long-term performance, learnability, memorability, most-used feature set, first impression, long-term satisfaction)
  - Reference values
  - Actual values (test data)
- Process of testing a UI (randomized tests)
  - Preparation
  - Introduction of test procedure to subjects
  - Test
  - Final discussion with subjects
  - Analysis
    - Quantitative, qualitative or subjective data
  - Report

3.2 Testing Process

Measurement function: $t = f(x, y, z, \ldots)$

- Independent variables (*x*, *y*, *z*,…) “**factors**”, parameters
  - Objects / systems under investigation (e.g., UI alternatives)
  - Variables can assume any value („**level**“) within the defined range
- **Dependent variables** (*t*, …)
  - Measured attributes / properties of the system (e.g., task completion time, error counts, survey answers, scores, …)
  - Functions of the independent variables
- **Confounding factors**
  - Additional factors (e.g., fatigue, learning) that can have an unintended influence on the dependent variables

3.2 Testing Process

Factorial design

- One-factor tests:
  - Only one independent variable *x* with l_x levels
    $\rightarrow l_x$ UI alternatives

Example:
Input device ε {mouse, arrows on keyboard, tangible 3D-object}
→ 3 UI alternatives

3.2 Testing Process

Factorial design

- Two-factor tests:
  - Two independent variables, *x* with l_x levels and *y* with l_y levels
    $\rightarrow l_x * l_y$ UI alternatives

Example:
Input device ε {mouse, arrows on keyboard, tangible 3D-object}
Output ε {sound, 3D graphics}
→ 3*2 = 6 UI alternatives

- N-factor tests: N independent variables …

3.3 Experiment Design

Test designs (comparing several UI alternatives)

- ***Between-subject design***
  Users are divided into several groups, each working with one UI alternative (i.e., with a different level of the independent variables)

Sample process of testing a UI (per test person)

- Demographic questionnaire
- Explain test scenario to test person
- Explain UI to test person
  - If necessary, let them play with the UI
- Test
  - Quantitative test
  - Qualitative test (questionnaire)
  - Interview
- Final discussion

Note: not all steps are executed in every experiment

3.3 Experiment Design

Test designs (comparing several UI alternatives)

- ***Within-subject design***
  All users are exposed to all UI alternatives
  - Less subjects required
  - Larger statistical strength: no bias due to different users
  - But: carry-over effects (learning, fatigue)
  - Permutations of test sequences required (for counterbalancing)
    → requires n! subjects to test n UI alternatives
  - common simplification: (**Latin Squares** requiring only n subjects)

A	B	C
B	C	A
C	A	B

A	B	C
C	A	B
B	C	A

Example:
Input device ε {mouse, arrows on keyboard, tangible 3D-object}
Output ε {sound, 3D graphics}
→ 6 UI alternatives
→ 720 test subjects

Example 2:
Input device ε {mouse, tangible 3D-object}
Output ε {sound, 3D graphics}
→ 4 UI alternatives
→ 24 test subjects

3.3 Experiment Design

Test designs (comparing several UI alternatives)

- *Within-subject design*

Sample process of testing a UI (per test person)
- Demographic questionnaire
- Explain test scenario to test person
- For every UI alternative (in randomized order):
  - Explain UI alternative to test person
    - If necessary, let them play with the UI
  - Test
    - Quantitative test
    - Qualitative test (questionnaire)
    - Interview
- Final discussion

Note: not all steps are executed in every experiment

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4.1 General Approach

How can we decide whether two UI alternatives are „different“ with respect to some criterion x?

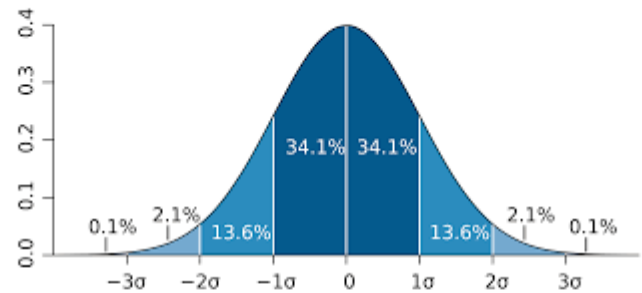
Hypothesis testing

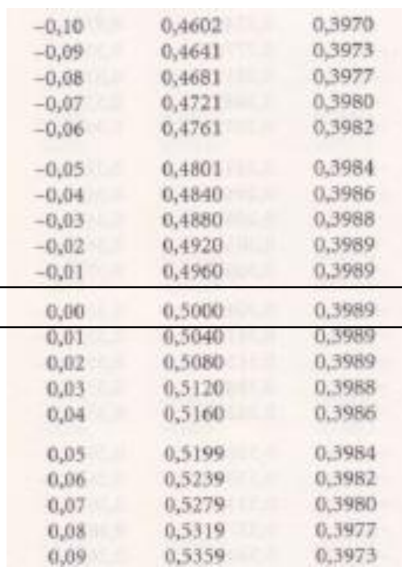
- Is UI *a* different from UI *b*?
- Is the difference significant?

4.2. Basics

Simulations

- (Normal) population
  - Mean μ
  - Variance σ^2
  - Standard deviation σ





Z	area	ordinate
−0,10	0,4602	0,3970
−0,09	0,4641	0,3973
−0,08	0,4681	0,3977
−0,07	0,4721	0,3980
−0,06	0,4761	0,3982
−0,05	0,4801	0,3984
−0,04	0,4840	0,3986
−0,03	0,4880	0,3988
−0,02	0,4920	0,3989
−0,01	0,4960	0,3989
0,00	0,5000	0,3989
0,01	0,5040	0,3989
0,02	0,5080	0,3989
0,03	0,5120	0,3988
0,04	0,5160	0,3986
0,05	0,5199	0,3984
0,06	0,5239	0,3982
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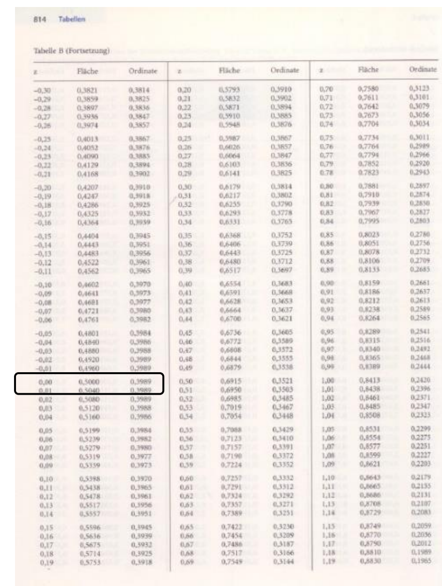
0,09	0,5359	0,3973

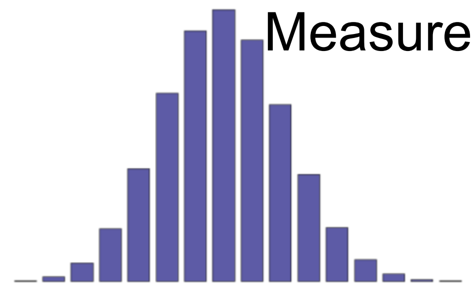


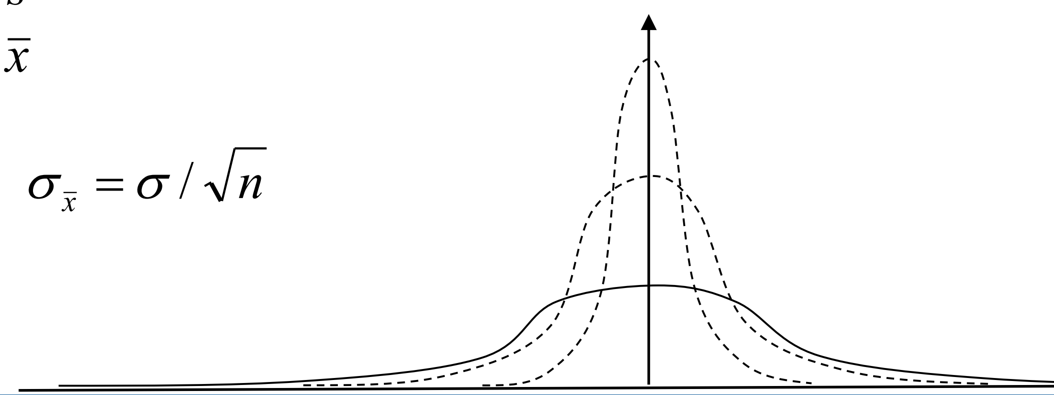
4.2 Basics

Simulations

- (Normal) population
  - Mean μ
  - Variance σ^2
  - Standard deviation σ
- Random samples
  - Observations n
  - Sample mean $\bar{x} = \sum x_i / n$
  - Sample variance $s^2 = \sum (x_i - \bar{x})^2 / (n-1)$
  - Sample standard deviation s
- Sampling distribution (s. d.) of $\bar{x}$
  - Mean of s. d. $\mu_{\bar{x}} = \mu$
  - Standard deviation of s. d. $\sigma_{\bar{x}} = \sigma / \sqrt{n}$
- Sample statistic
  - z, t, χ^2, F

Measurements





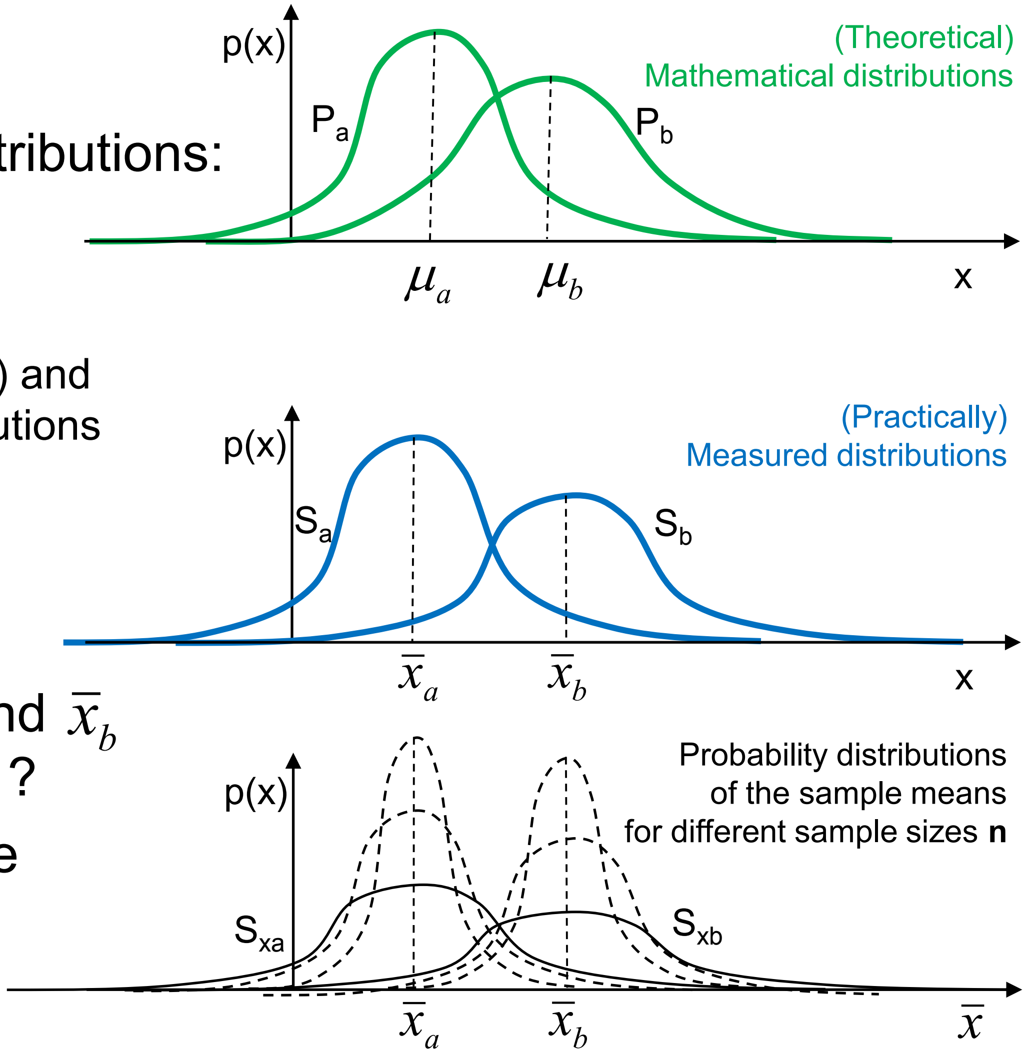
$\bar{x}$

4.2 Basics

- Two unknown probability distributions:

  $P_a : (\mu_a, \sigma_a^2) \qquad P_b : (\mu_b, \sigma_b^2)$
- Are they different?
  - Depends on shapes (variances) and positions (means) of the distributions
- Must be estimated from two sampling distributions:

  $S_a : (\bar{x}_a, s_a^2) \qquad S_b : (\bar{x}_b, s_b^2)$
- Are the sample means $\bar{x}_a$ and $\bar{x}_b$ good estimates of μ_a and μ_b?
- Probability distributions of the sample means



4.3 Test Procedure

- Two sampling distributions:

  $S_a : (\bar{x}_a, s_a^2), \; S_b : (\bar{x}_b, s_b^2)$

- Null hypothesis H_0:
  There is only one distribution

  $P_a : (\mu_a, \sigma_a^2) \quad \mu_a = \mu_b$

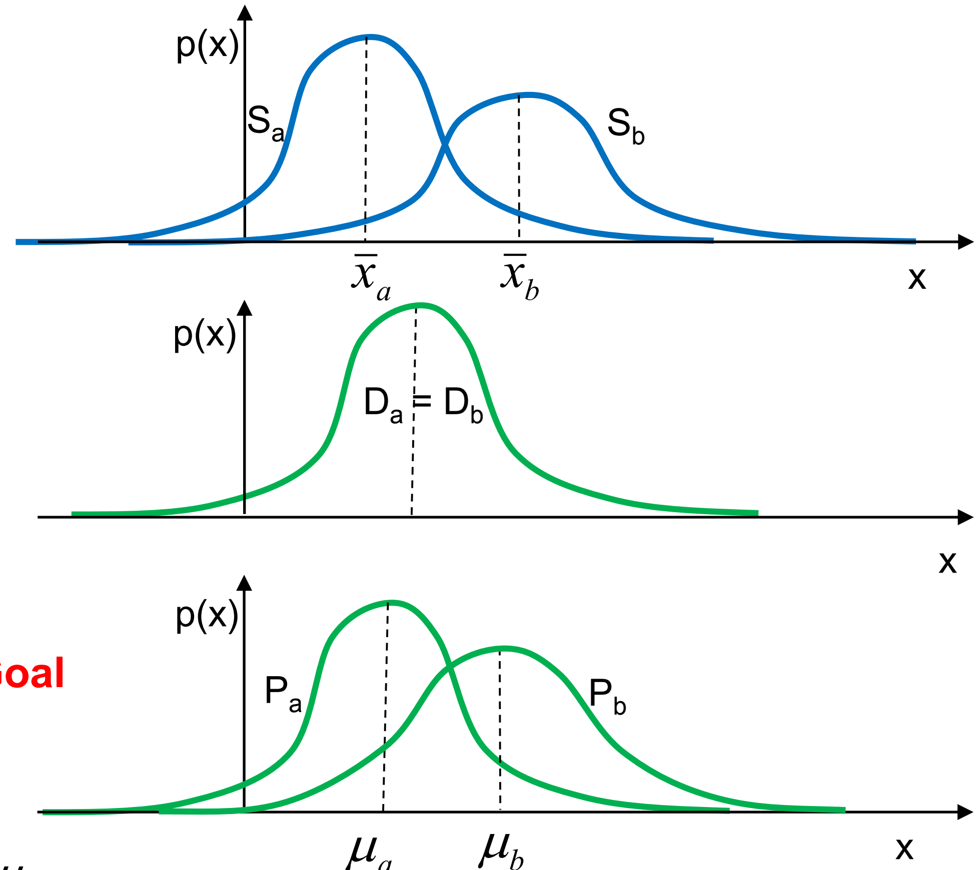
- Alternate hypothesis H_1:

  Distributions are different:

  $P_a : (\mu_a, \sigma_a^2) \quad P_b : (\mu_b, \sigma_b^2)$

  - Two-sided $\mu_a \neq \mu_b$
  - One-sided $\mu_a < \mu_b \quad or \quad \mu_a > \mu_b$

Goal



Indirect proof:
Prove H_1 by showing that it is extremely unlikely that H_0 is true.

4.3 Test Procedure

- Two sampling distributions:

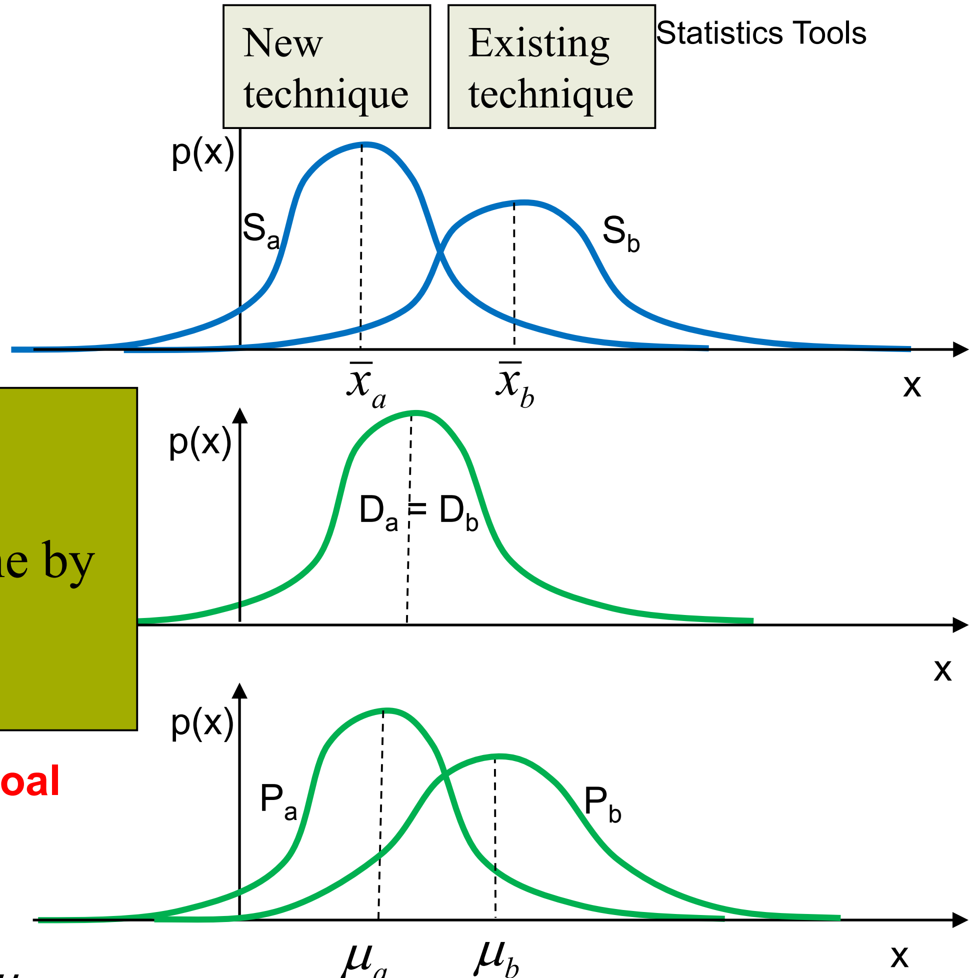
  $S_a : (\bar{x}_a, s_a^2),\ S_b : (\bar{x}_b, s_b^2)$

Example:
Prove that a new interaction technique is faster (or slower) than an existing one by showing that it is extremely unlikely that both are equally fast.

Distributions are different: **Goal**

$P_a : (\mu_a, \sigma_a^2) \qquad P_b : (\mu_b, \sigma_b^2)$

- Two-sided $\mu_a \neq \mu_b$
- One-sided $\mu_a < \mu_b \quad or \quad \mu_a > \mu_b$

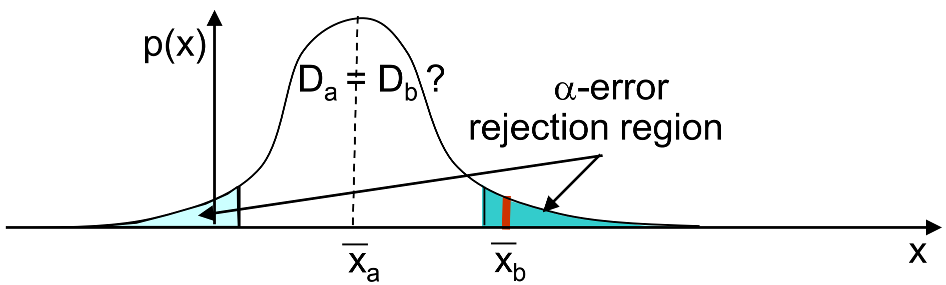


Indirect proof:
Prove H_1 by showing that it is extremely unlikely that H_0 is true.

4.3 Test Procedure

Indirect proof:
Prove H_1 by showing that it is extremely unlikely that H_0 is true.

- Evaluation of the null hypothesis H_0
  There is only one distribution: $\mu_a = \mu_b$

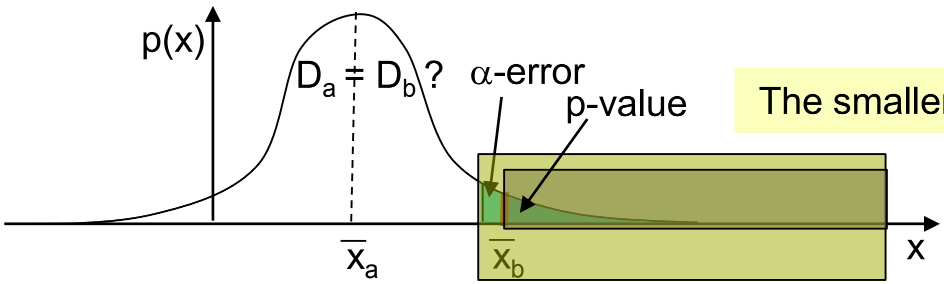


- Define a “rejection region” for H_0
- If x_b lies in the “rejection region”, it is highly unlikely that $\mu_a=\mu_b$
- → **Reject hypothesis H_0**: $\mu_a = \mu_b$ and thus conclude that $H_1 : \mu_a \neq \mu_b$ (or $\mu_a < \mu_b$ *or* $\mu_a > \mu_b$, resp.) is true
- Risk that we make a wrong decision (reject H_0 even though it is true): α-error (type I error)

Decision at significance level α

4.3 Test Procedure

α-error versus p-value



α-error:

- Fixed percentage (5% = 0.05) of the area under the curve
- Preselected value to indicate what kind of risk will be taken

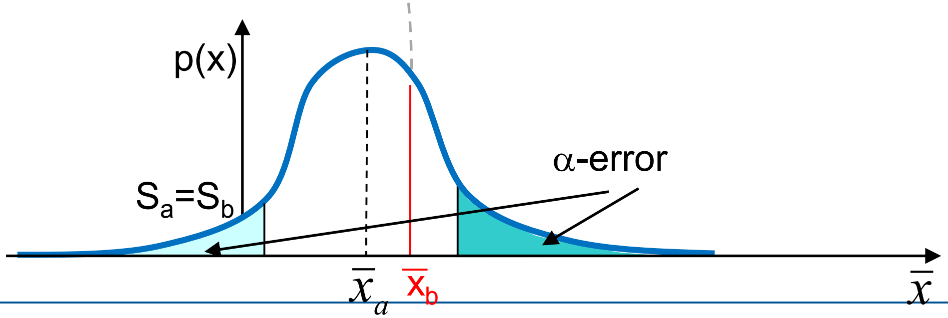
p-value:

- Computed percentage (depends on x_b) of the area under the curve
- If $p<\alpha$: reject Nullhypothesis

4.3 Test Procedure

α-error

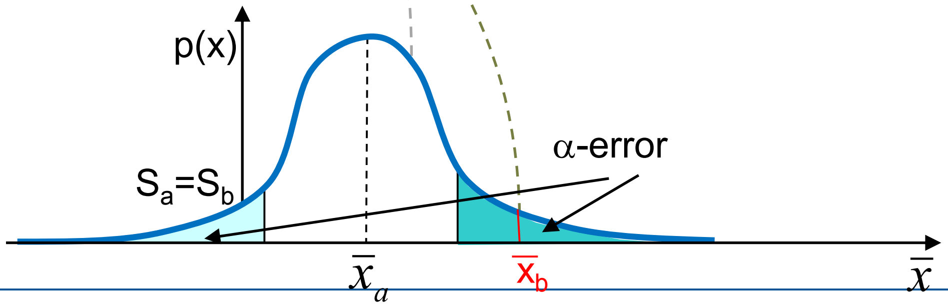
	"Real" H_0	"Real" H_1
Estimated H_0	Correct (wasted time)	?
Estimated H_1		



4.3 Test Procedure

α-error

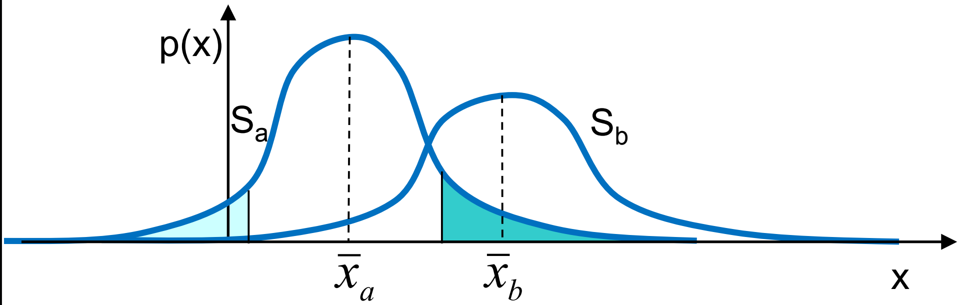
	"Real" H_0	"Real" H_1
Estimated H_0	Correct (wasted time)	Type II error β-error
Estimated H_1	Type I error α-error	Correct



4.3 Test Procedure

New technique | Existing technique | Statistics Tools

Example:
Prove that a new interaction technique is faster than an existing one (H_1) by showing that it is extremely unlikely that both are equally fast (H_0).



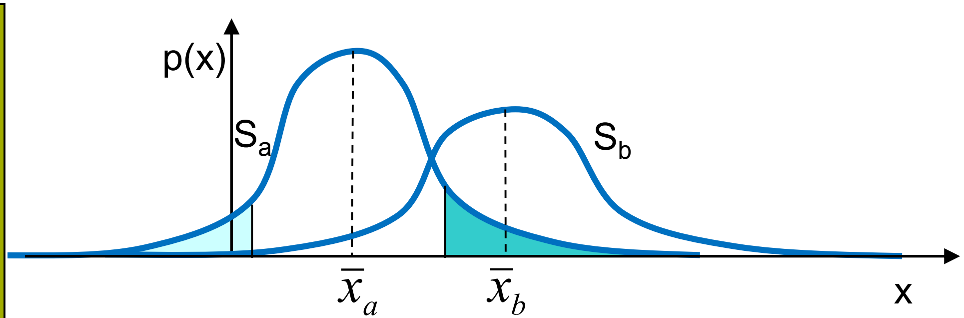
4.3 Test Procedure

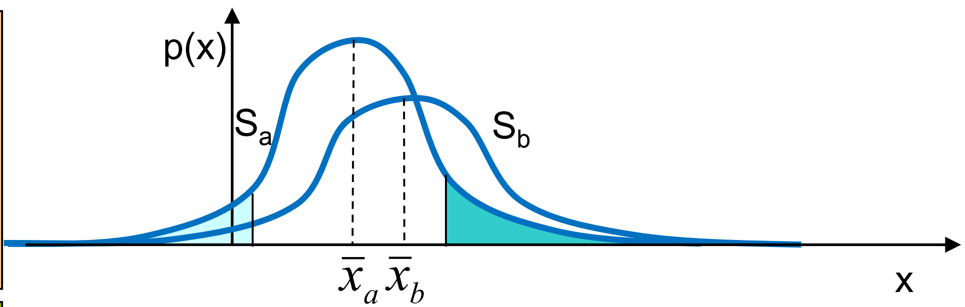
New technique | Existing technique | Statistics Tools

Example:
Prove that a new interaction technique is faster than an existing one (H_1) by showing that it is extremely unlikely that both are equally fast (H_0)

NOTE: WE CANNOT CONCLUDE THE INVERSE.
I.e.: If we cannot disprove H_0, we cannot conclude that H_1 is not true

Example:
If D_b is NOT in the rejection region, we cannot conclude that the new technique is NOT faster





New technique | Existing technique

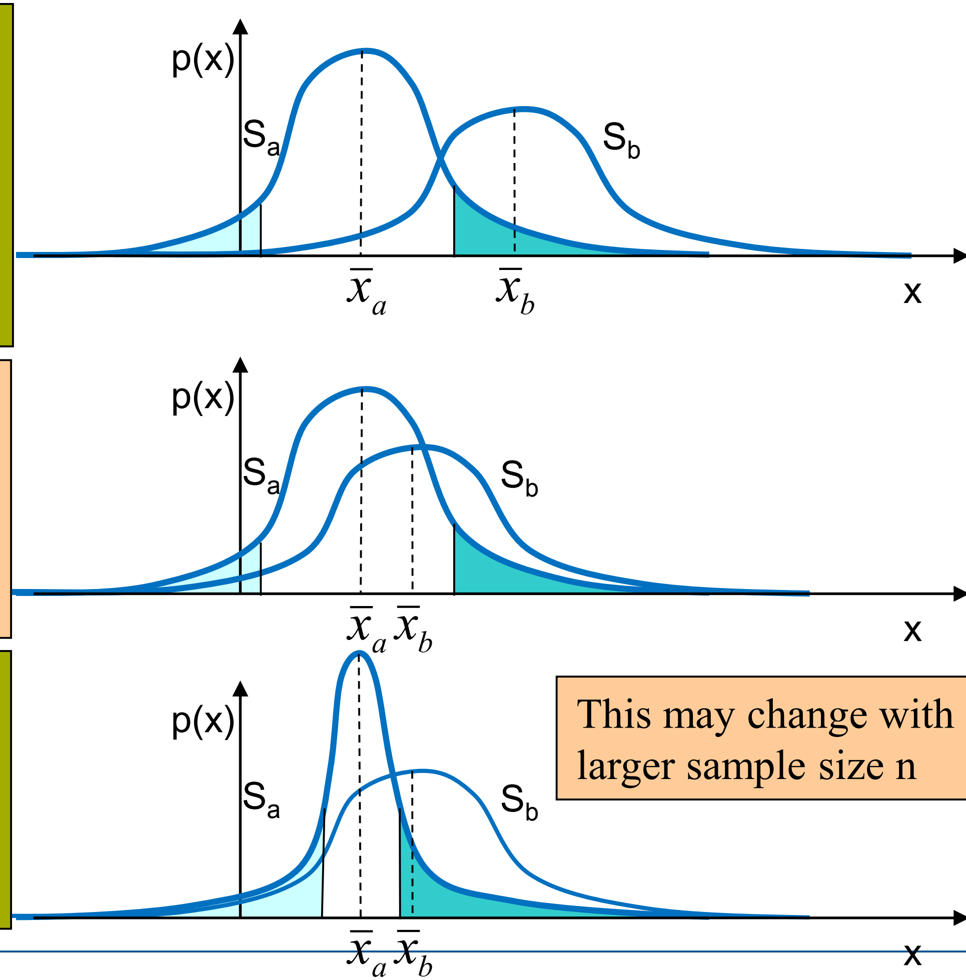
Statistics Tools

4.3 Test Procedure

Example:
Prove that a new interaction technique is faster than an existing one (H_1) by showing that it is extremely unlikely that both are equally fast (H_0)

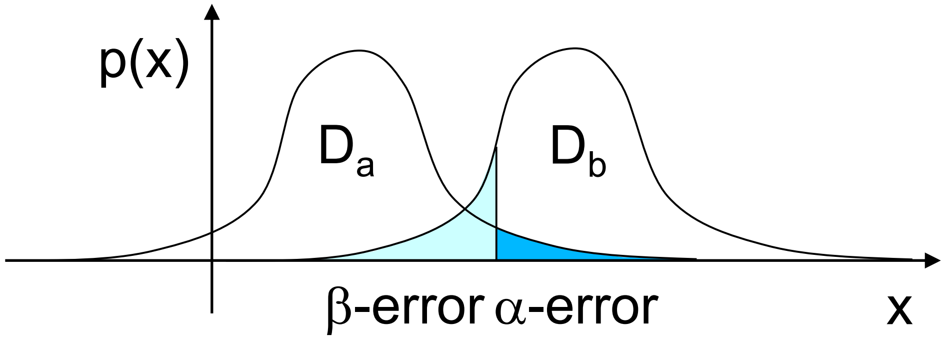
NOTE: WE CANNOT CONCLUDE THE INVERSE.
I.e.: If we cannot disprove H_0, we cannot conclude that H_1 is not true

Example:
If D_b is NOT in the rejection region, we cannot conclude that the new technique is NOT faster



4.3 Test Procedure

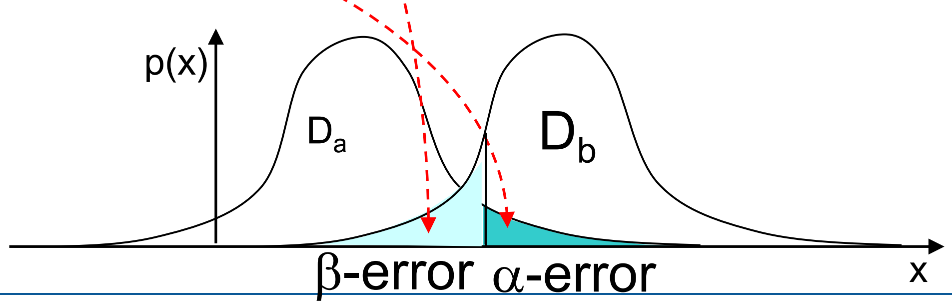
- Problem: You can avoid making mistakes by always accepting H_0 (by reducing α-error → 0) “no risk no fun”
- What if H_0 is wrongly accepted (should have been rejected)?



4.3 Test Procedure

β-error

	“Real” H_0	“Real” H_1
Estimated H_0	Correct (wasted time)	Type II error β-error
Estimated H_1	Type I error α-error	Correct



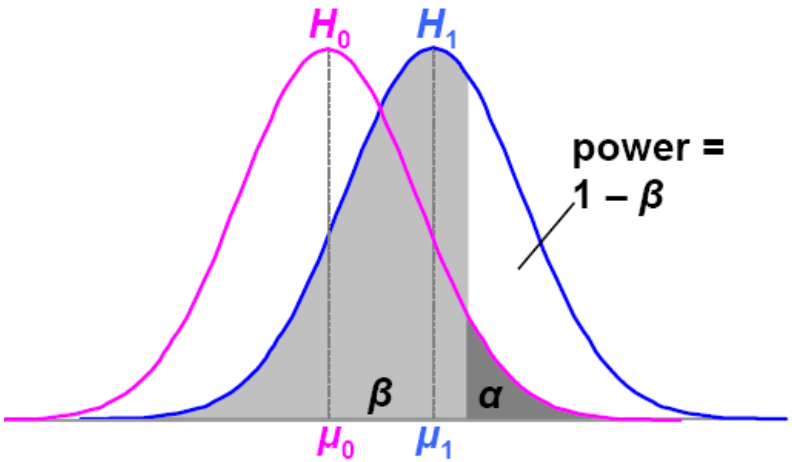
4.4 Interpretation of Test Results

	"Real" H_0	"Real" H_1
Estimated H_0	Correct (wasted time)	Type II error β-error
Estimated H_1	Type I error α-error	Correct

Power

Probability that a test will reject a false null hypothesis H_0

I.e.: that it will accept a correct alternate hypothesis H_1



Figures from Slides: J. Swan, S. Ellis, B. Adelstein, "Conducting Human-Subject Experiments with Virtual and Augmented Reality", IEEE VR 2007.

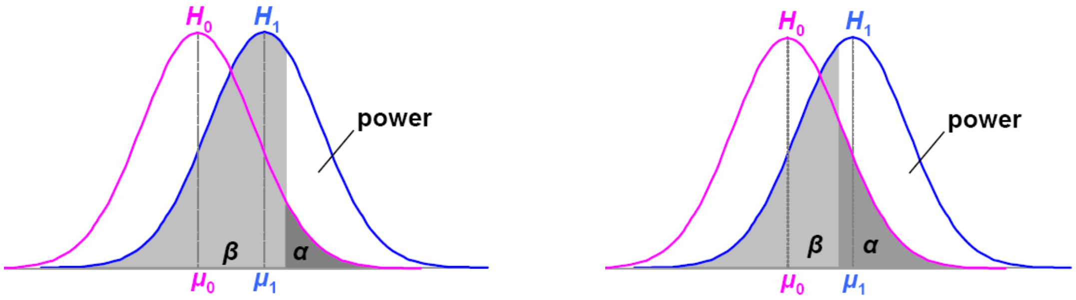
4.4 Interpretation of Test Results

	“Real” H_0	“Real” H_1
Estimated H_0	Correct (wasted time)	Type II error β-error
Estimated H_1	Type I error α-error	Correct

Dependence of power on **α-level**

Increasing $\alpha \rightarrow$

- Increasing power
- Decreasing type II error
- Increasing type I error



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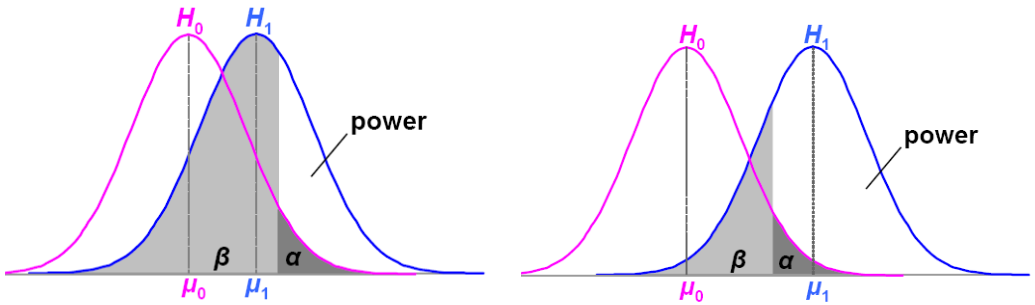
4.4 Interpretation of Test Results

	“Real” H_0	“Real” H_1
Estimated H_0	Correct (wasted time)	Type II error β-error
Estimated H_1	Type I error α-error	Correct

Dependence of power on **effect** (difference between μ_0 and μ_1)

Large effect →

- Increasing power
- Decreasing type II error
- Unaffected α and type I error



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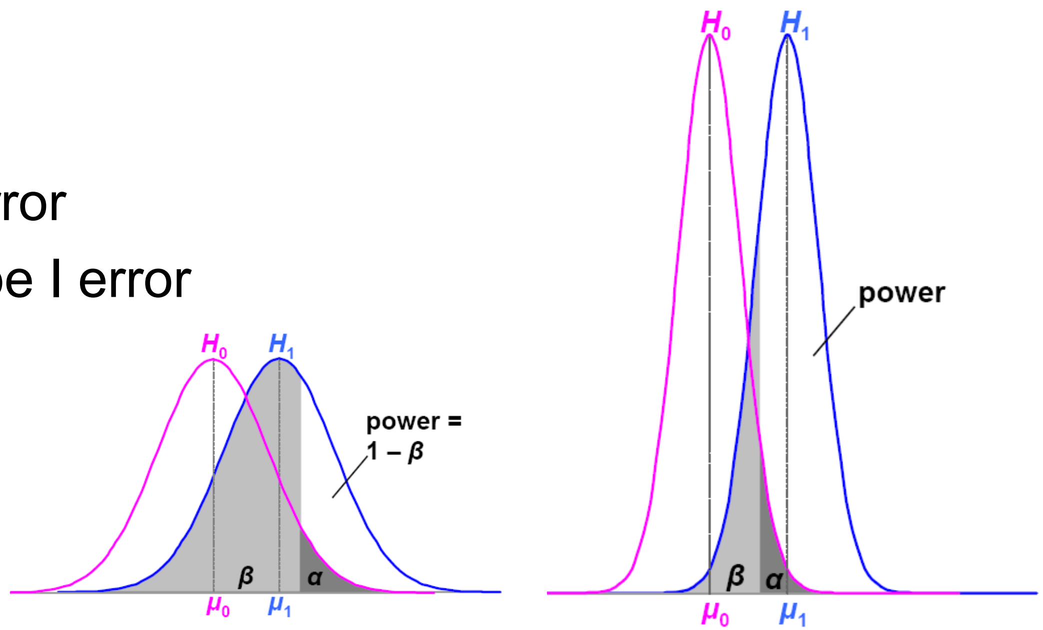
4.4 Interpretation of Test Results

	“Real” H_0	“Real” H_1
Estimated H_0	Correct (wasted time)	Type II error β-error
Estimated H_1	Type I error α-error	Correct

Dependence of power on **sample size n**

Increasing sample size n →

- Decreasing variance
- Increasing power
- Decreasing type II error
- Unaffected α and type I error



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Thank you!