

# Cognitive Neuroscience for AI Developers

## Psychology – Historical Approaches



# What is psychology?

- Psychology is the **scientific** study of mind and behavior.
  - Internal mental events: perception, reasoning, language, visual imagery
  - External events: behavior, speech
  - Scientific Method (only modern Psychology, not like Philosophy)
- Many competing theories
  - Voluntarism
  - Structuralism **Cataloging “stuff” in our head**
  - Functionalism
  - Gestalt theory
  - Psychoanalytic psychology
  - Behaviorism



Source: wikipedia.org

Wilhelm Wundt (German physiologist and psychologist, seated) with colleagues in his psychological laboratory, the first of its kind.

# The psychological approach to Cognitive Science

- Psychology as a science since late 19th century
- Relatively young discipline compared to philosophy
- Relatively old discipline compared to AI and robotics
- First discipline to study mental phenomena with scientific methods
- Broad field with many subdisciplines and competing theories

# Excursus: Motivation

- **Psychology of 19<sup>th</sup> century:** Why learn this old stuff?
- Major ideas and techniques are still relevant today!

## Sparks of Artificial General Intelligence: Early experiments with GPT-4

Sébastien Bubeck    Varun Chandrasekaran    Ronen Eldan    Johannes Gehrke  
Eric Horvitz    Ece Kamar    Peter Lee    Yin Tat Lee    Yanzhi Li    Scott Lundberg  
Harsha Nori    Hamid Palangi    Marco Tulio Ribeiro    Yi Zhang

Microsoft Research

# Excursus: Motivation

- **For example how do we measure intelligence of LLM as GPT4**
  - **Normally:** test AI system on benchmark data sets
  - **However:** This does not work ->we do not know the whole training data-> perhaps has seen every benchmark data set
  - Benchmark data sets are not valid to test creativity
  - ***“To overcome the limitations described above, we propose here a different approach to studying GPT-4 which is closer to traditional psychology rather than machine learning, leveraging human creativity and curiosity.” (Bubeck et al. 2023)***
  - -> some kind of novel IQ test are applied

Bubeck, S., Chandrasekaran, V., Eldan, R., Gehrke, J., Horvitz, E., Kamar, E., ... & Zhang, Y. (2023). Sparks of artificial general intelligence: Early experiments with gpt-4. *arXiv preprint arXiv:2303.12712*.

# Excursus: Motivation

- **Examples 1: Combine arts and programming “Produce javascript code which generates random images in the style of the painter Kandinsky”**

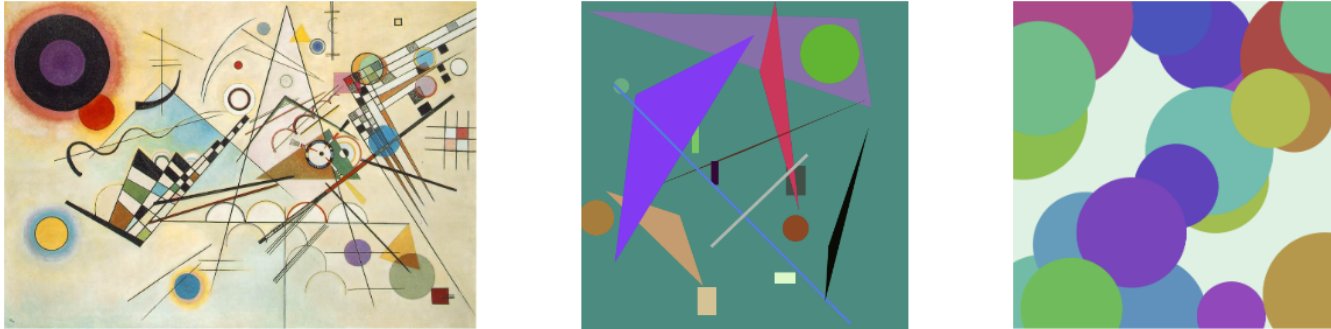


Figure 2.1: The first image is Composition 8, art by Wassily Kandinsky, the second and the third are produced by GPT-4 and ChatGPT respectively with the prompt “Produce Javascript code that creates a random graphical image that looks like a painting of Kandinsky”.

Bubeck, S., Chandrasekaran, V., Eldan, R., Gehrke, J., Horvitz, E., Kamar, E., ... & Zhang, Y. (2023). Sparks of artificial general intelligence: Early experiments with gpt-4. *arXiv preprint arXiv:2303.12712*.

# Excursus: Motivation

- **Examples 2: Theory of Mind (ability to attribute mental states such as beliefs, emotions, desires, intentions, and knowledges to others)**
- **-> high cognitive function (tested with Sally-Ann false belief test)**

## GPT-4: Understanding beliefs

We will read about a scenario, and then have a question and answer session about it.

--

Scenario:

Alice and Bob have a shared Dropbox folder.

Alice puts a file called 'photo.png' inside /shared\_folder/photos.

Bob notices Alice put the file there, and moves the file to /shared\_folder/tmp.

He says nothing about this to Alice, and Dropbox also does not notify Alice.

--<|endofprompt|>

Q: After the call, Alice wants to open 'photo.png'. In which folder will she look for it?

Alice will most likely look for 'photo.png' in /shared\_folder/photos, the folder where she originally put it. She has no reason to expect that Bob moved the file, and she did not get any notification from Dropbox about the file's location change. Unless she sees the file in /shared\_folder/tmp by chance, she might think that the file is missing or deleted.

# Excursus: Motivation

- **Nowadays: Psychology is becoming important for AI research** -> e.g. to measure intelligence of AI systems
- Reminder: Psychology is the **scientific** study of mind and behavior.  
-> Scientific method

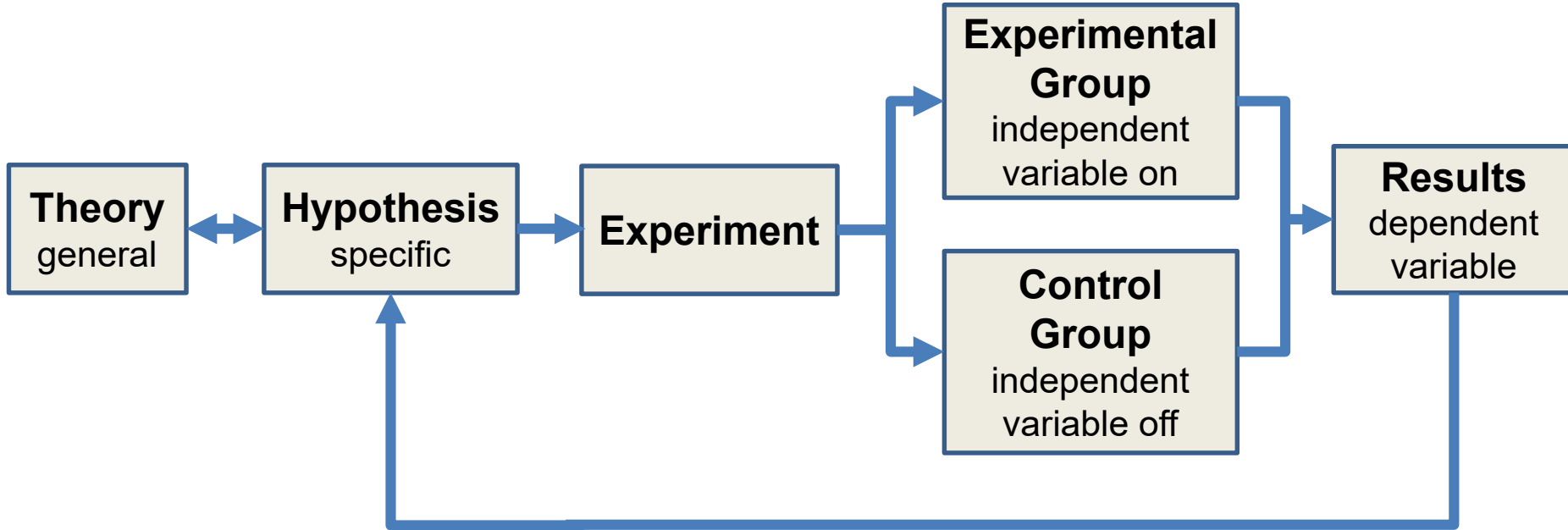
End of Excursus



# Psychology and the scientific method

- Early psychologist relied on **introspection** and **phenomenology**
- **Main methods (now):**  
questionnaires, surveys, case study analysis, recording of behavior
- **Scientific method (Hypothetic-Deductive-Approach)**
  - Experiments to test hypotheses
  - Hypotheses testing to construct or adjust theories
  - Theories to generate new hypotheses
- **Experiments**
  - **Independent variable:** manipulated by experimenter
  - **Dependent variable:** what is measured or observed
  - **Minimum of two conditions:** experimental group vs control group

# Psychology and the scientific method



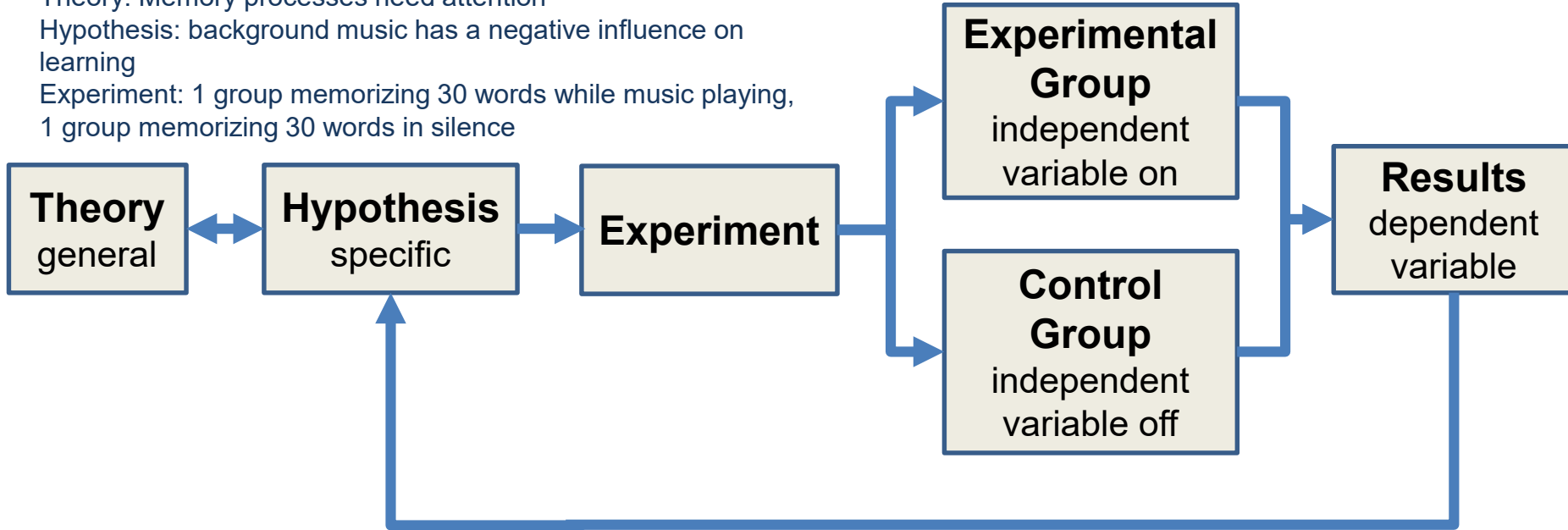
# Psychology and the scientific method

Example:

Theory: Memory processes need attention

Hypothesis: background music has a negative influence on learning

Experiment: 1 group memorizing 30 words while music playing,  
1 group memorizing 30 words in silence



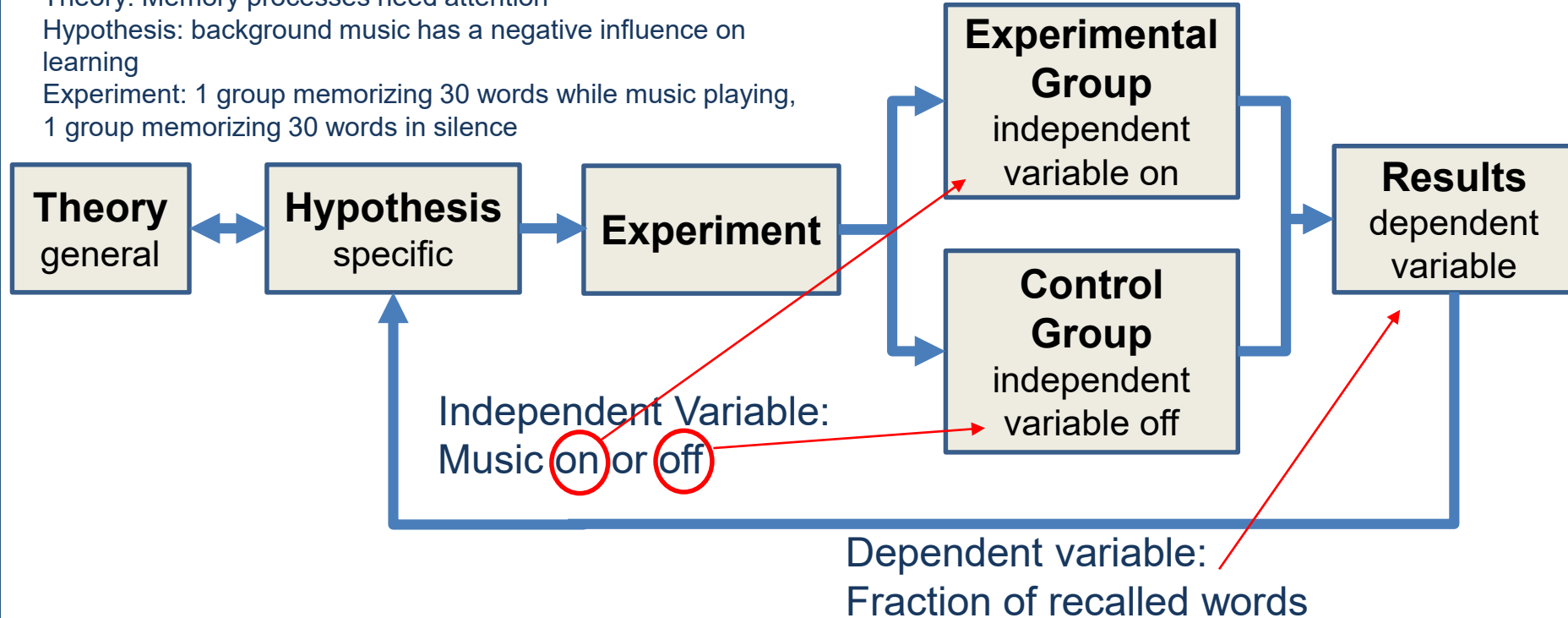
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**Attention:** There are other potential factors that have on unwanted effect

- e.g. day time: strategy **randomize** the assignment of participants
- e.g. age of participants, strategy: **counterbalance** the age of participants
- **systematic errors** are not taken into account by statistical testing (personal experience: systematic errors underestimated)
- **statistical tests** (e.g. t-tests) are used to find out if an effect might be caused just by randomness or not,  $p\_value < 5\%$  defined as significant  $\rightarrow$  real effect

# Psychology and Statistical testing

Major errors in science (QRPs: questionable research practices):

- **P-Hacking:** Selection of data (e.g. outlier removal) and statistical tests in order to make non-significant results significant
- **HARKing:** Hypothesizing after results are known (post-hoc hypothesis)

If you do not take care: Replicability Crisis:

- Results cannot be reproduced (36%-68%)

Head, M. L., Holman, L., Lanfear, R., Kahn, A. T., & Jennions, M. D. (2015). The extent and consequences of p-hacking in science. *PLoS biology*, 13(3), e1002106.

Kerr, N. L. (1998). HARKing: Hypothesizing after the results are known. *Personality and social psychology review*, 2(3), 196-217.

Brachem, J., Frank, M., Kvetnaya, T., Schramm, L. F., & Volz, L. (2022). Replikationskrise, p-hacking und Open Science. *Psychologische Rundschau*.

Pashler, H., & Harris, C. R. (2012). Is the replicability crisis overblown? Three arguments examined. *Perspectives on Psychological Science*, 7(6), 531-536.

## Is the Replicability Crisis Overblown? Three Arguments Examined

Harold Pashler and Christine R. Harris  
University of California, San Diego



Perspectives on Psychological Science  
7(6) 531-536  
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SAGE

# Intelligence tests

- Psychology was not only interested in understanding the mind but started early to **measure** it
- Intelligence test were developed over a century ago
  - **Alfred Binet** developed methods to measure intelligence to improve France's education system
  - 1920 Binet's test were adapted by **Lewis Terman** at Stanford university to measure intelligence of students -> Stanford-Binet Intelligence Quotient (IQ) has been influential ever since
- Cultural bias in the test
  - e.g. task to name different coins -> advantage for rich people
- IQ tests were reworked several times (to reduce cultural bias)

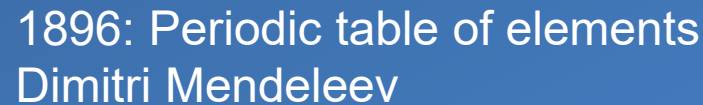


# Intelligence tests

Still critiques of IQ-Test:

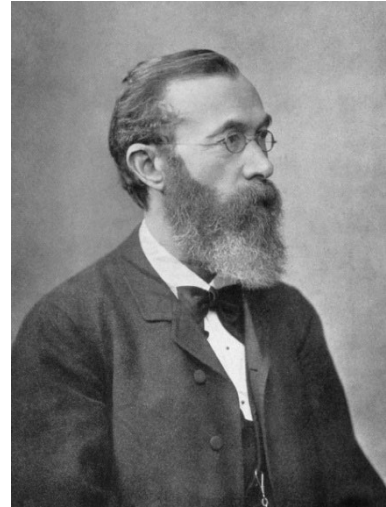
IQ test assumes that:

- a) **general intelligence is innate** -> not true  
-> In twin studies it was shown that IQ can improve when children are moved to intellectual supportive environment
- b) **intelligence can be measured with one number** -> there are different aspect of intelligence  
-> Howard Gardner (2011) -> **different types of intelligence** (at least eight):  
linguistic intelligence, musical intelligence, logical-mathematical intelligence,  
bodily-kinesthetic intelligence (athletes), interpersonal intelligence (sales persons),  
intra personal intelligence (self-knowledge)...



# Voluntarism

- **Mind consists of mental elements** assembled into higher cognitive components **through the power of will** (= voluntary effort of the mind)
- **Goal:** Periodic table of mental elements (influenced by chemistry)
- **Method:** Introspection („inward looking“)
  - Look inward to identify mental elements
  - Presented students colored objects and asked for their experiences
  - Wundt wanted to systemize introspection: students were put in state of attention and experiments were repeated several times



Source: wikipedia.org

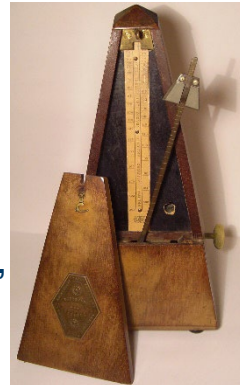
Wilhelm Wundt  
1832-1920  
German Psychologist

# Voluntarism

- **Wundt wanted to study consciousness**
- **Two types of conscious experience**
  - **Immediate experience:** direct awareness of something  
(we see a red rose) -> Wundt's focus
  - **Mediate experience:** mental reflection  
(mental reflections about an object, e.g. tell someone about rose)
- **„Tridimensional theory of feeling“** -> all feelings characterized by three dimensions (experiments with metronome)  
Pleasure – Displeasure (certain rhythm), Tension – Relaxation (waiting for click) ,  
Excitement – Depression (change of tempo)

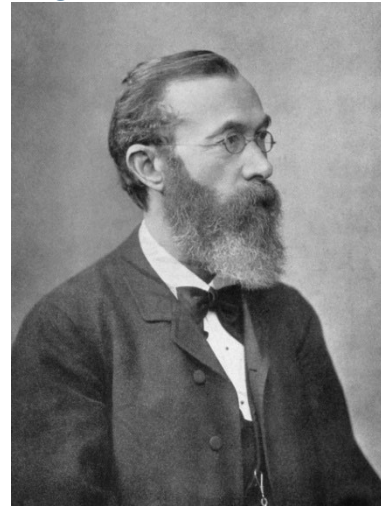


Source: wikipedia.org  
Willhelm Wundt 1832-1920



# Summary and Critique of Voluntarism

- Beneficial as Voluntarism was the first (scientific) attempt to studying the mind
- However: Introspection is a problematic method
  - mental experiences change over time
  - act of introspecting changes experiences
- Wundt was never able to find a list of mental elements comparable to the periodic table of elements -> far too long list

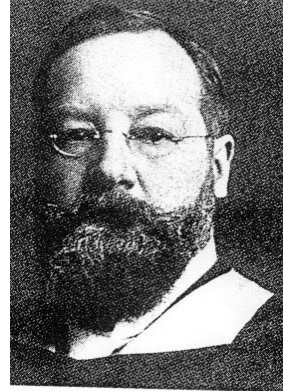


Source: wikipedia.org

**Wilhelm Wundt**  
1832-1920

# Structuralism – What the mind is

- Shares some ideas with voluntarism, Subject matter: Conscious experience
- **Mind as passive agent**, with mental elements combining according to mechanistic laws
- **Titchener wanted to avoid the Stimulus Error**: confusing true experience with description of that object based on language and previous experiences -> **only well trained observers can accurately introspect**
- **Three goals of psychology**:
  - Describe consciousness in terms of most basic components
  - Discover the laws by which these components associate
  - Understand relation between elements and psychological conditions



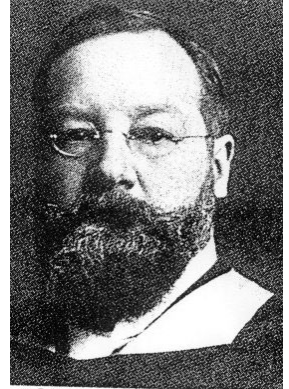
Source: wikipedia.org

Edward Bradford  
Titchener  
1867-1927  
American  
psychologist

# Structuralism – What the mind is

- **Combination of elements not affected through active will,**  
The mind as a passive mechanism or substrate within which elements are combined according to a set of laws (mind is a reagent, sometimes participants were called reagents)

**Reagent is a substance added  
to a mixture to produce a  
chemical reaction**



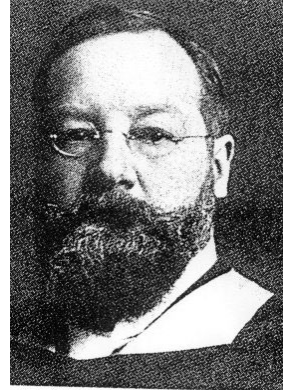
Source: wikipedia.org

Edward Bradford  
Titchener  
1867-1927

- **Total of 44,000 sensation elements described** (Titchener, 1896) -> same problem as Wundt
- **Sensations can be characterized by four attributes:** quality, intensity, duration, clearness (sensation one pays attention to), later also extensity (extent to which sensation fills space -> pressure from pencil vs. chair bottom)

# Summary and Critique of Structuralism

- Same points of criticism as for **Voluntarism**
- **Difference to Voluntarism:** Refinement of experimental procedures -> **Training of study participants biases responses even more**
- **Over-emphasized mental elements** and ignore holistic perception



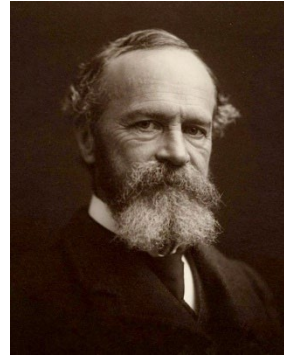
Source: wikipedia.org

Edward Bradford  
Titchener  
1867-1927



# Functionalism – What the mind does

- **Focuses on what the mind can do** (not on mental elements)
- **Mental processes and functions** instead of mental elements
- **The mind as a stream of consciousness** (not mind as elements): mind is a process undergoing continuous change (term still used -> see later lectures)
- **Substantive thought** occurs when mind slows down (focus attention, in contrast to transitive thought)
- **Transitive thoughts**: less focused form of thinking



Source: wikipedia.org

William James  
1842-1910  
American  
psychologist

# Functionalism – What the mind does

- **Three major themes of functionalism** (proposed by Rowland Angell, 1907):
  - **Mental operations** (how mental process operates, what is accomplished under which conditions they occur)
  - **Fundamental utilities of consciousness**  
(role of consciousness for survival of the organism)
  - **Psychophysical relations** (relation of the psychological mind and the physical body)
- Strongly influenced by **Darwin**'s theory of natural selection (how did the mind develop under evolutionary pressure)
- Precursor of **Evolutionary Psychology** (*"the study of behavior, thought, and feeling as viewed through the lens of evolutionary biology"*) <https://www.britannica.com/science/evolutionary-psychology>

# Summary and Critique of Functionalism

- **Wide variety of methods:** e.g. questionnaires, objective behavioral descriptions, but also introspection
- **No clear definition of the word function**
  - 1) function refers to an process itself (perception and memory)
  - 2) function refers to the usefulness of the process  
(e.g. how does memory contribute to survive)
- **Too practical:** Often too focused on usefulness of function
  - Structuralism vs. Functionalism (Fight which is better basic or applied science)

# Gestalt psychology

„The whole is greater than the sum of its parts.“



Source: wikipedia.org

**Max Wertheimer**  
1880-1943



Source: www.uni-giessen.de

**Kurt Koffka**  
1886-1941



Source: psychestudy.com

**Wolfgang Kohler**  
1887-1967

# Gestalt psychology

„The whole is greater than the sum of its parts.“ (Gestalt = Integrated whole)

- **As functionalism counterreaction to structuralism** -> Conscious wholes cannot be reduced into parts (physics analogy: mental parts combined into wholes is the same as particles ordered in a field of force)
- **Main method:** Phenomenology (subjective experience, observers describe subjective experience, in contrast to introspection phenomenology focuses on **immediate subjective perception**)
- Greatest contribution of Gestalt psychology in **perception and learning** (looser in methodology e.g. observed animals finding solutions)

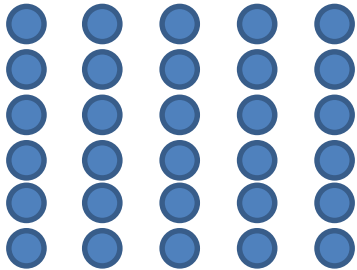
# Gestalt psychology

*„I stand at the window and see a house, trees, sky. Theoretically, I might say there were 327 brightnesses and nuances of color. Do I have 327? No. I have sky, house, and trees.“ (Max Wertheimer)*

## Gestalt principles of perceptual organization (Max Wertheimer)

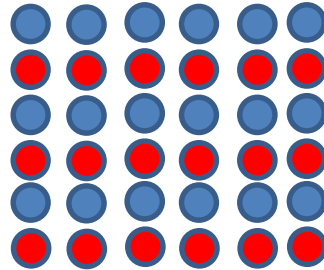
(ways in which visual parts group to form objects)

Just a few principles!



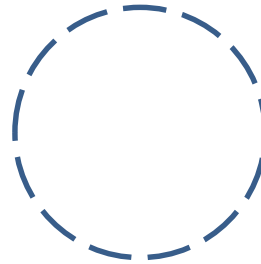
Parts that are closer  
tend to be connected

**Proximity**



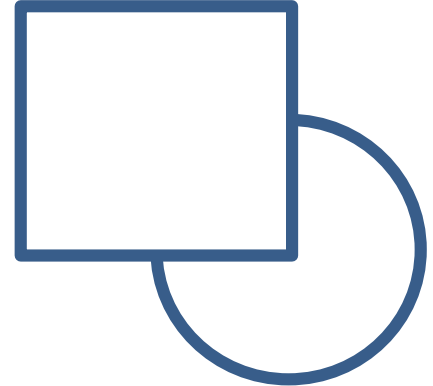
Parts that are similar  
tend to be connected

**Similarity**



Parts that form a (nearly)  
Complete object go together

**Closure**



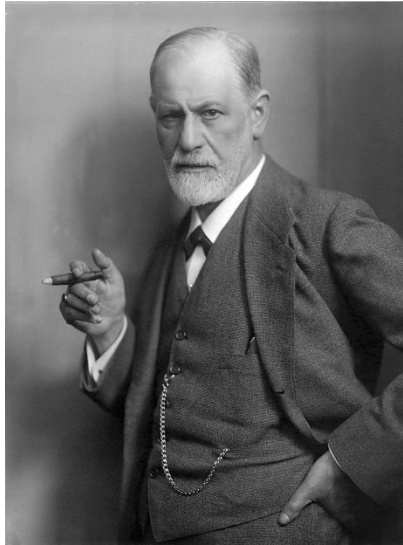
Parts that are simple  
will group together

**Pragnanz**

# Summary and Critique of Gestalt Psychology

- Phenomenology approach **lacks scientific rigor**
- Data was not gained in experimental settings so there was **no statistical analysis**
- Principles of perceptual organization are just descriptive but do not provide explanations

# Psychoanalytic psychology



Source: wikipedia.org

Sigmund Freud  
1856-1939

The mind is made up of „miniature minds“ that compete with each other for control of behavior.



Source: britishpsychotherapyfoundation.org.uk

## Three-tiered system of consciousness

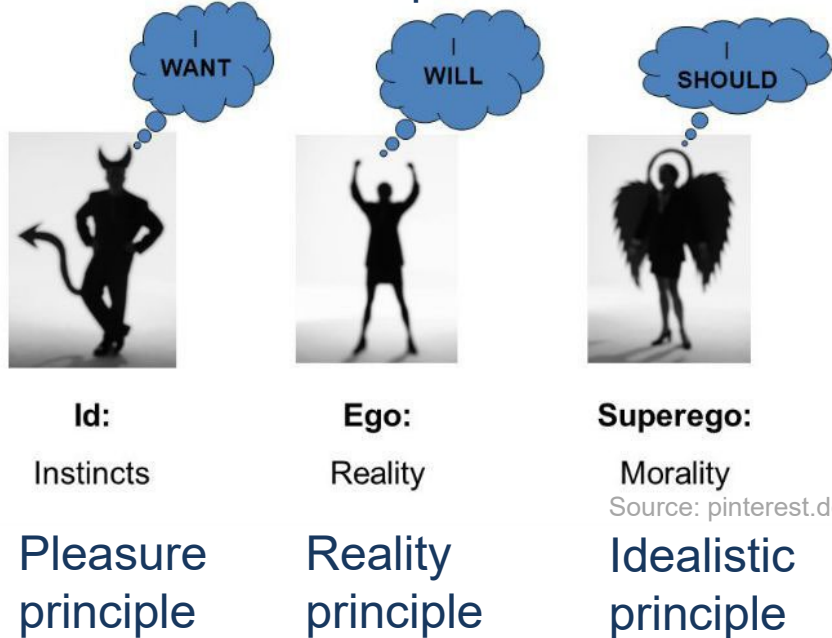
- **Conscious mind** (contains thoughts and feelings which we are aware of, home address)
- **Pre-conscious mind** (thoughts we can bring to consciousness with efforts, recall what one did last Friday)
- **Unconscious mind** (thoughts and experiences that can never be brought to consciousness, childhood memories)



# Psychoanalytic psychology

Three other mental structures with different operation modes

- **Id** contains unconscious impulses and desires (e.g. hunger) -> wants to attain gratification for desires immediately
- **Super ego** is responsible for ethical sense -> motivates the individual to act morally
- **Ego** balances the demands of super ego and id -> operates in a pragmatic way



# Psychoanalytic psychology



Source: simple.wikipedia.org

- Link the three mental structures (id, super ego, ego) to three-tiered system of consciousness: metaphor of iceberg
- **Id** is completely unconscious and powerful
- **Super-ego** tries to suppress the needs of the id
- **Ego** tries to balance needs of super ego and id
- **If ego fails to satisfy one -> anxiety**
- Ego constructs defense mechanism to shield itself against anxiety
  - **Repression:** banishing of anxiety arousing thoughts from consciousness
  - **Sublimation:** transform of unacceptable impulses in socially valued motivations

**Freuds model of the mind as machine with interacting parts -> he used many terms from mechanics and electronics**

# Summary and critique of Psychoanalytic psychology

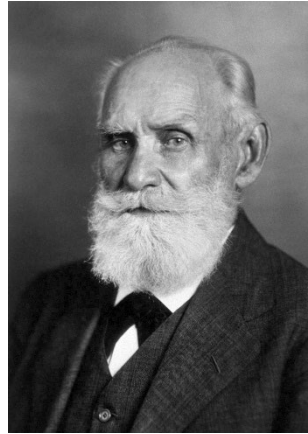
- Approach stimulated further research in the area of unconscious processes and inspired generations in clinical practice
- **Critique:** Freud overestimated parental and early childhood influence
- **Scientific shortcomings:** theory not based on objective observations but on notes about Freud's patients
- Freud's ideas have no predictive power

# Behaviorism – The mind as a black box



Source: wikipedia.org

**Edward L. Thorndike**  
1874-1949



Source: wikipedia.org

**Ivan Pavlov**  
1849-1936

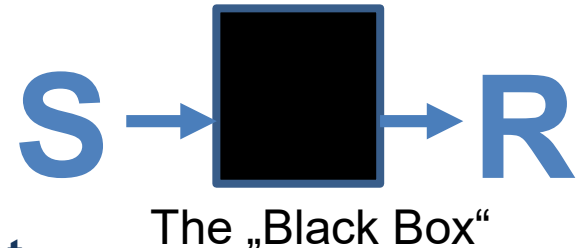


Source: wikipedia.org

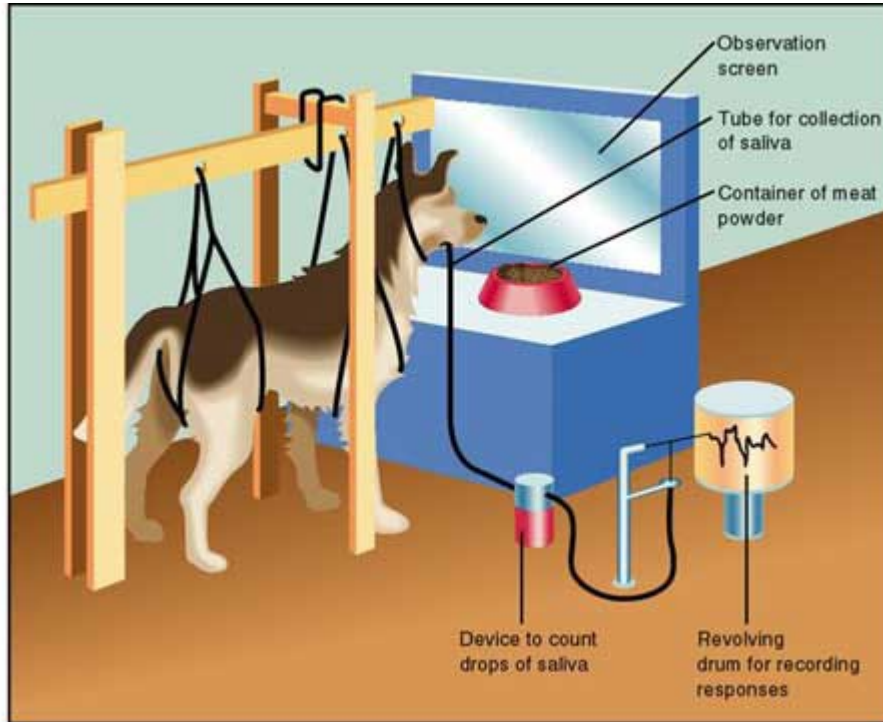
**Burrhus F. Skinner**  
1904-1990

# Behaviorism – The mind as a black box

- Mind is **too complex** to be studied scientifically
- Behaviorists thought that the **scientific method** cannot be applied to the mind (no good technique) -> behavioral experiments
- Behaviorism influenced by animal research
- Humans were lumped in the same category as animals -> more general/natural science
- Behaviorists rejected introspection
- Most important stimuli are **reward and punishment**

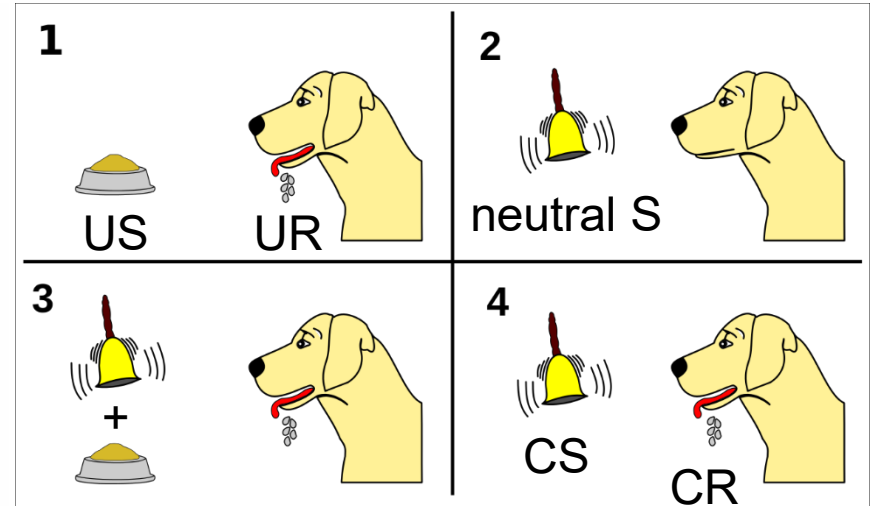


# Behaviorism – Classical conditioning



Source: simplypsychology.org

Just built-in reflexes of animals



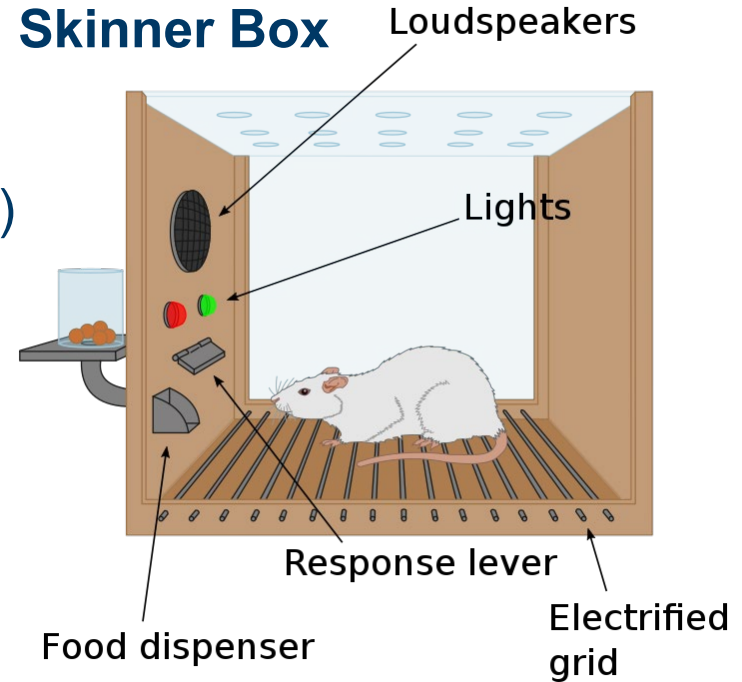
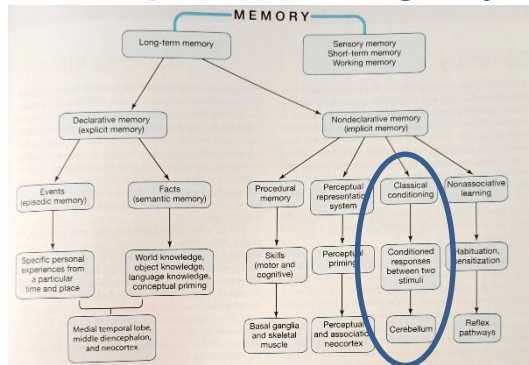
Source: wikipedia.org

US: Unconditioned Stimulus  
UR: Unconditioned Response  
CS: Conditioned Stimulus  
CR: Conditioned Response

# Behaviorism – Operant conditioning

## Learning through

- **Reinforcement**  
(anything that increases the frequency of the response, e.g. by food)
- **Punishment** (decreases the frequency of responses, e.g. by electric shock)



Source: wikipedia.org

# Behaviorism – Summary and Criticism

- **Strength:** completely objective science of behavior, rigorous scientific methods
- Behaviorism was the dominant paradigm until the 1960s -> **rise of cognitive psychology**
- Edward Chance Tolman (1886-1959) found out that reward and **punishment is not necessary for learning** -> he challenged classical doctrine of behaviorism -> rats can navigate through maze after exploration (no reward or punishment) -> **latent learning**



# Summary of the psychological approach

- **Historical:** many different theoretical positions and schools of thought
- Psychology is the **first discipline** to systematically apply experiments to study mind
- Initially **lack of precision** and reliance on **non-scientific methods**
- Initially **no overarching theory or framework**

## Today

- Cognitive approach and information-processing perspective  
  
-> Cognitive Psychology and Cognitive Neuroscience