Feedback, core of cybernetics

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Courtesy: Zdeněk Kotek, Petr Vysoký

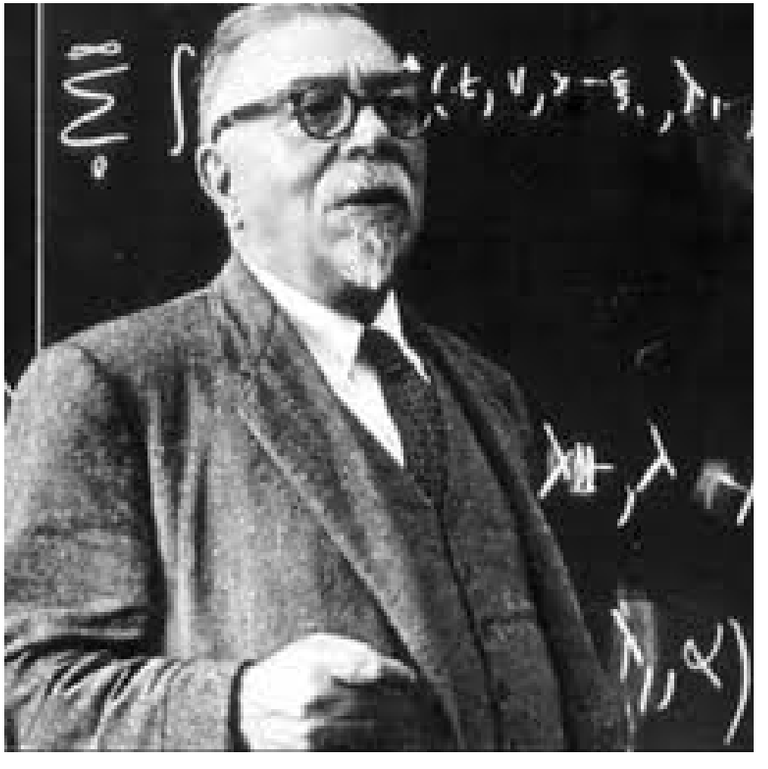
Outline of the talk:

- Feedback informally.
- Norbet Wiener.
- A system perspective.
- Four important principles.
- Engineering cybernetics history, Tsien Hsue-Shen.
- Cybernetics history in the East Europe.
- Feedback control, influence to errors.

Feedback, introduction

- Merriam-Webster dictionary:
  1. The partial reversion of the effects of a process to its source or to a preceding stage.
  2. The transmission of evaluative or corrective information about an action, event, or process to the original or controlling source;

     Also: the information so transmitted.
- Unlike in modeling-based open-loop control of dynamic systems, the feedback weakens the need for precise models.
- Formalized by Norbert Wiener in 1948.
- The feedback concept is much older, though.

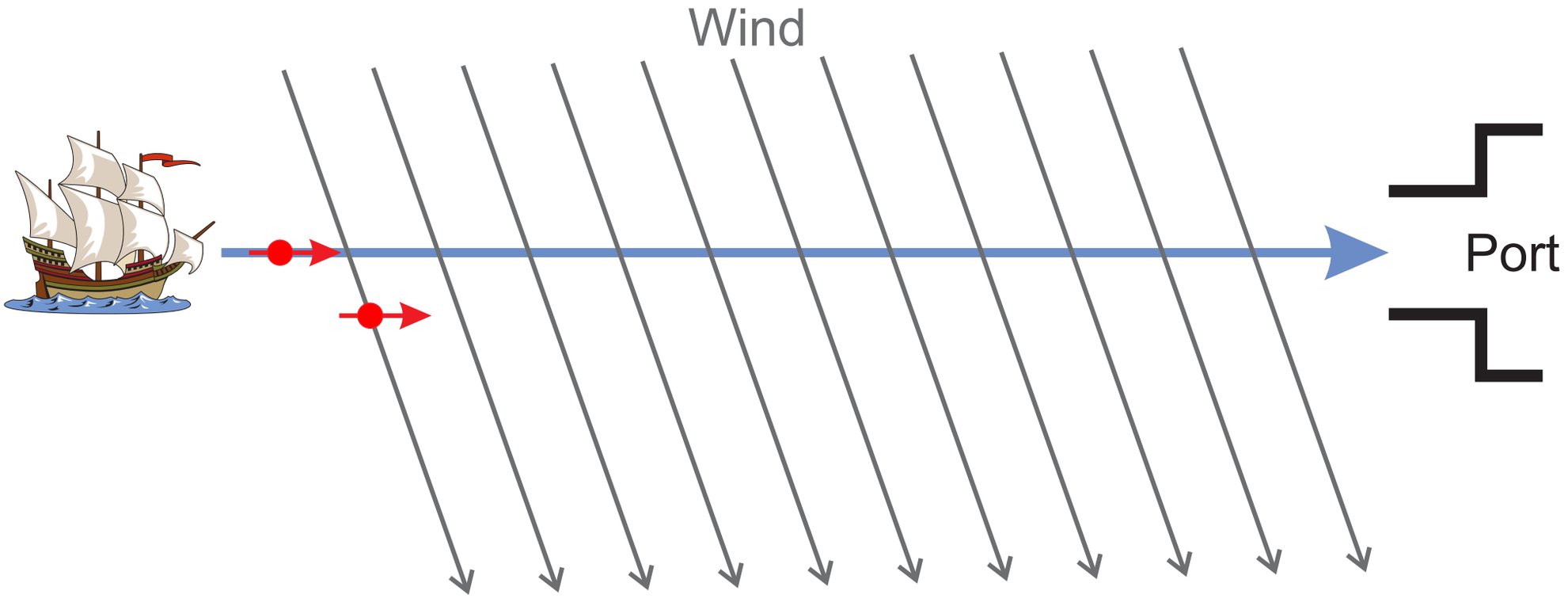


Norbert Wiener
1894 - 1964

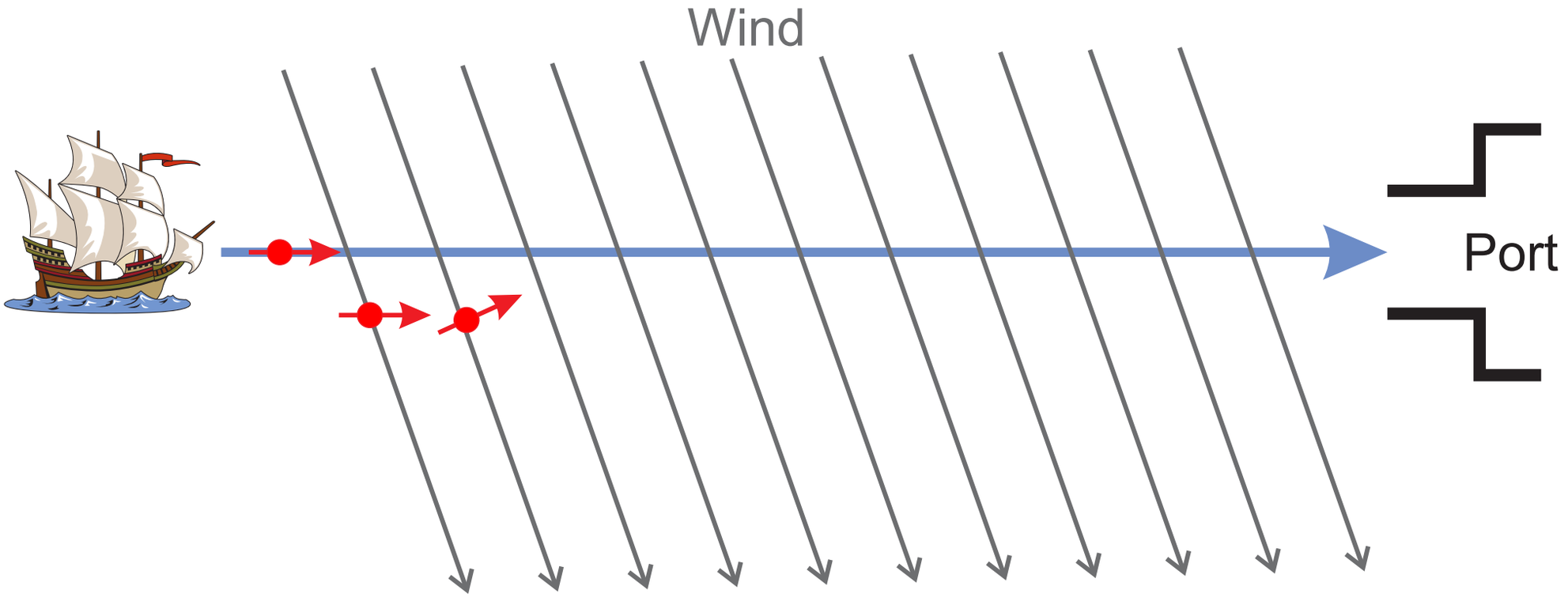
Steersman example

Steersman example

Steersman example



Steersman example



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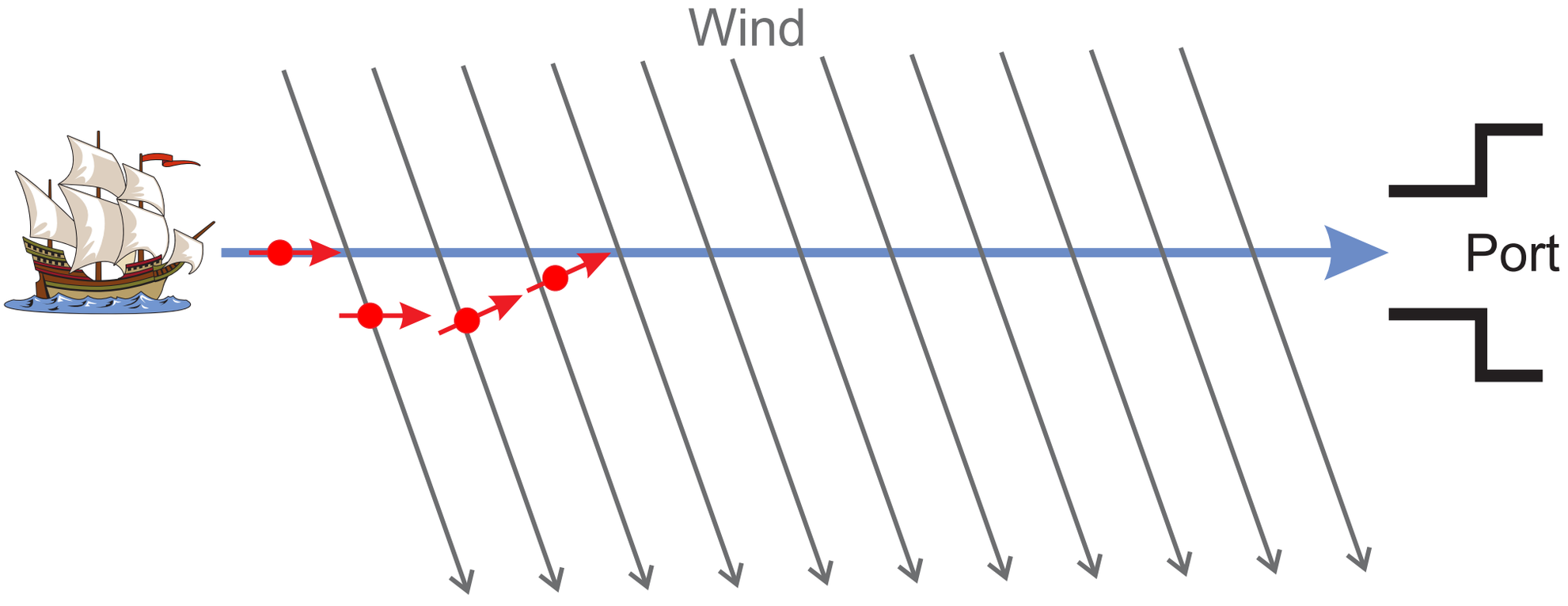

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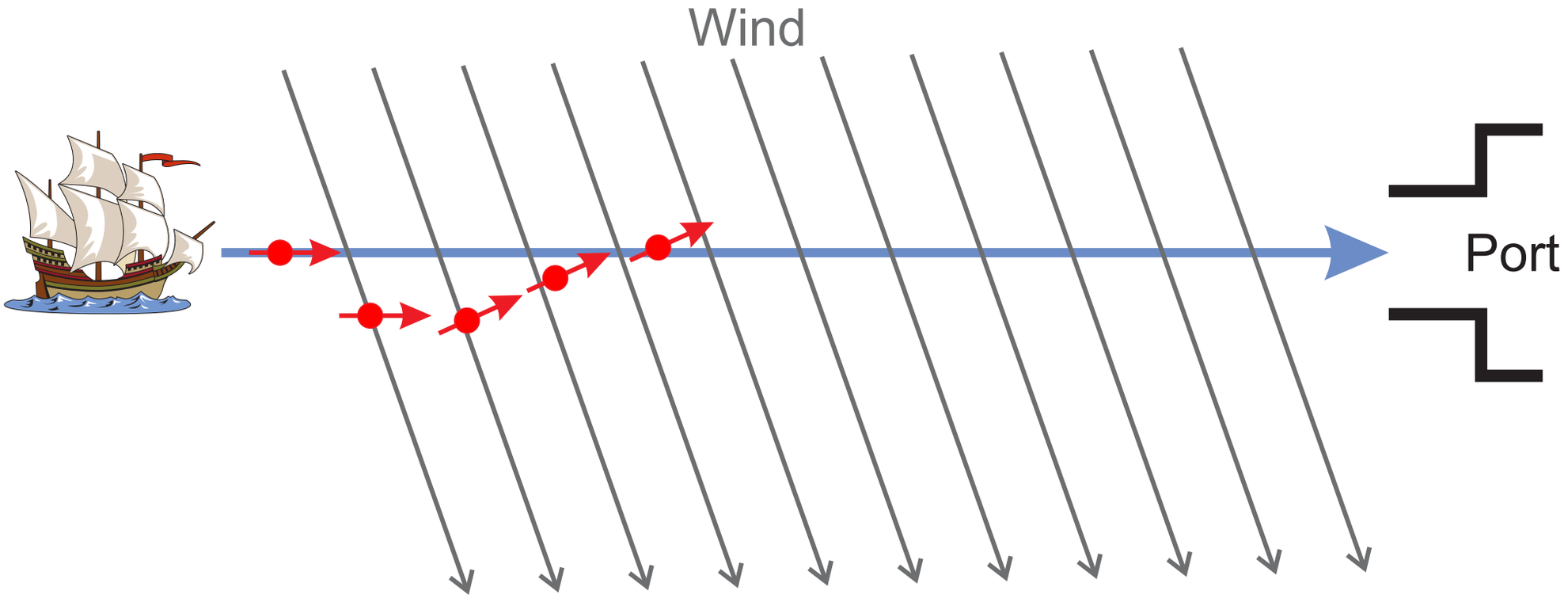

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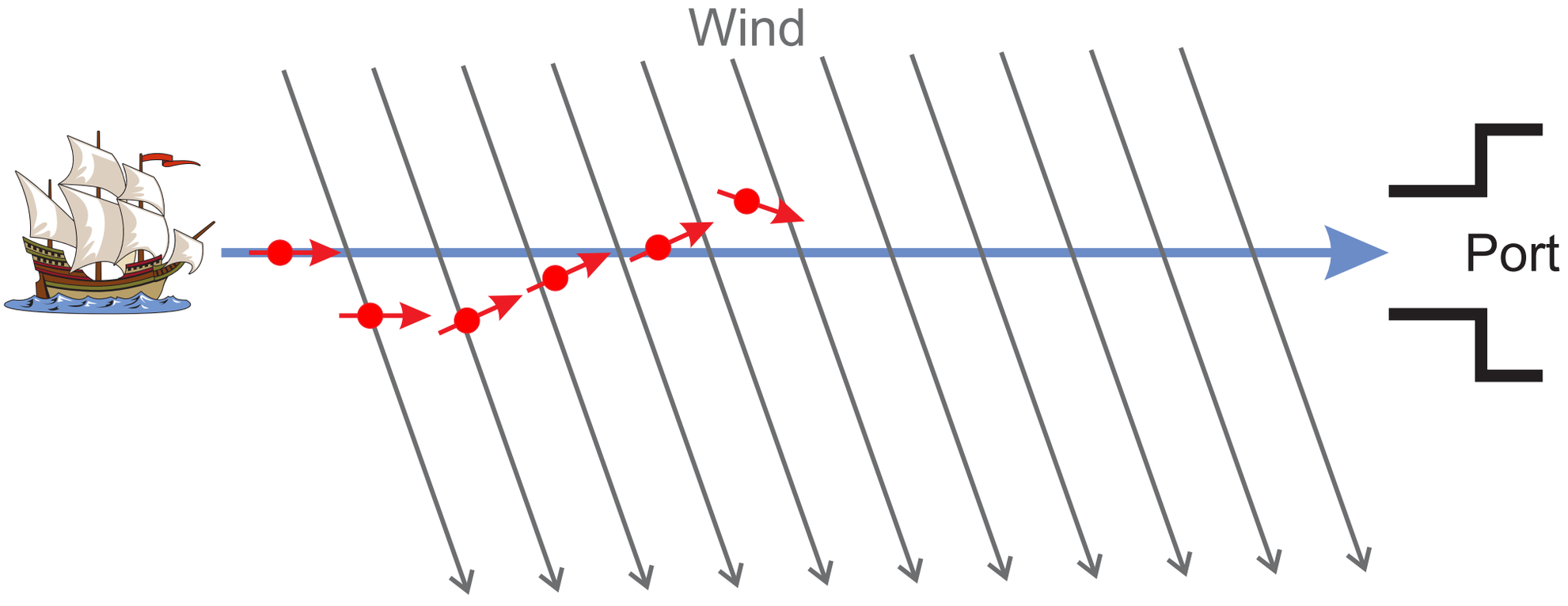

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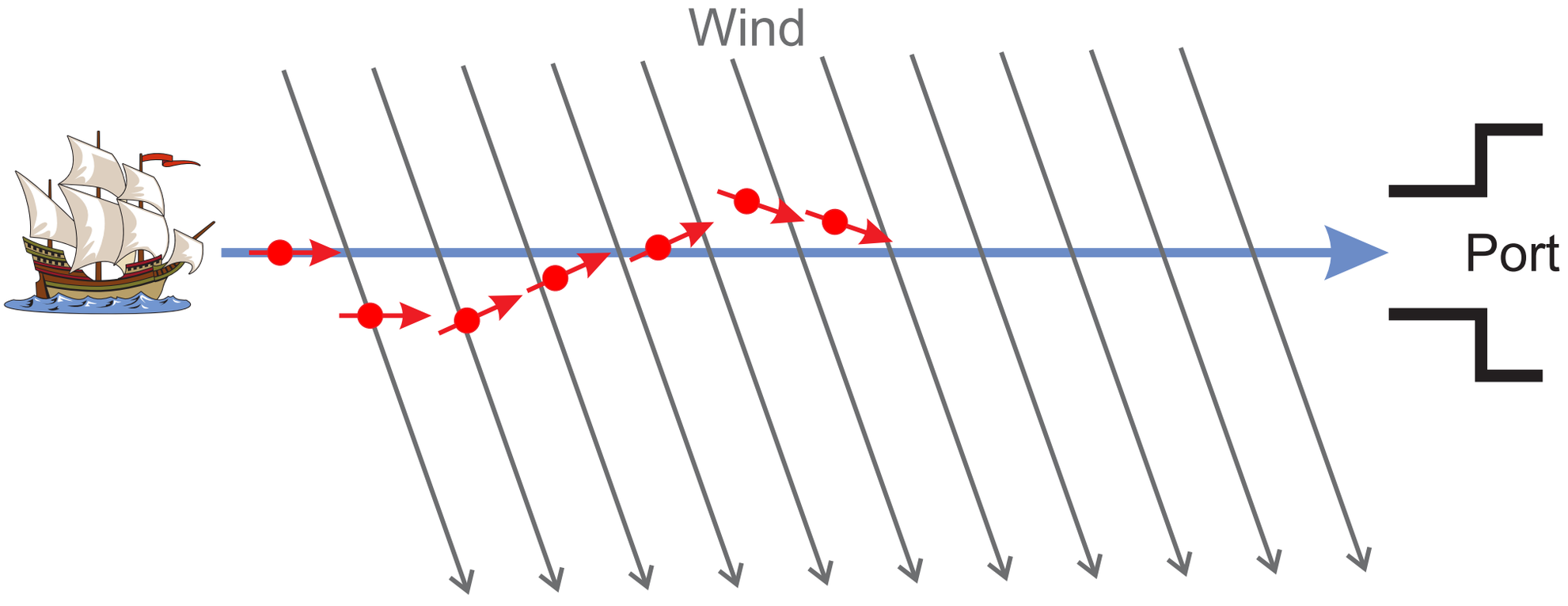

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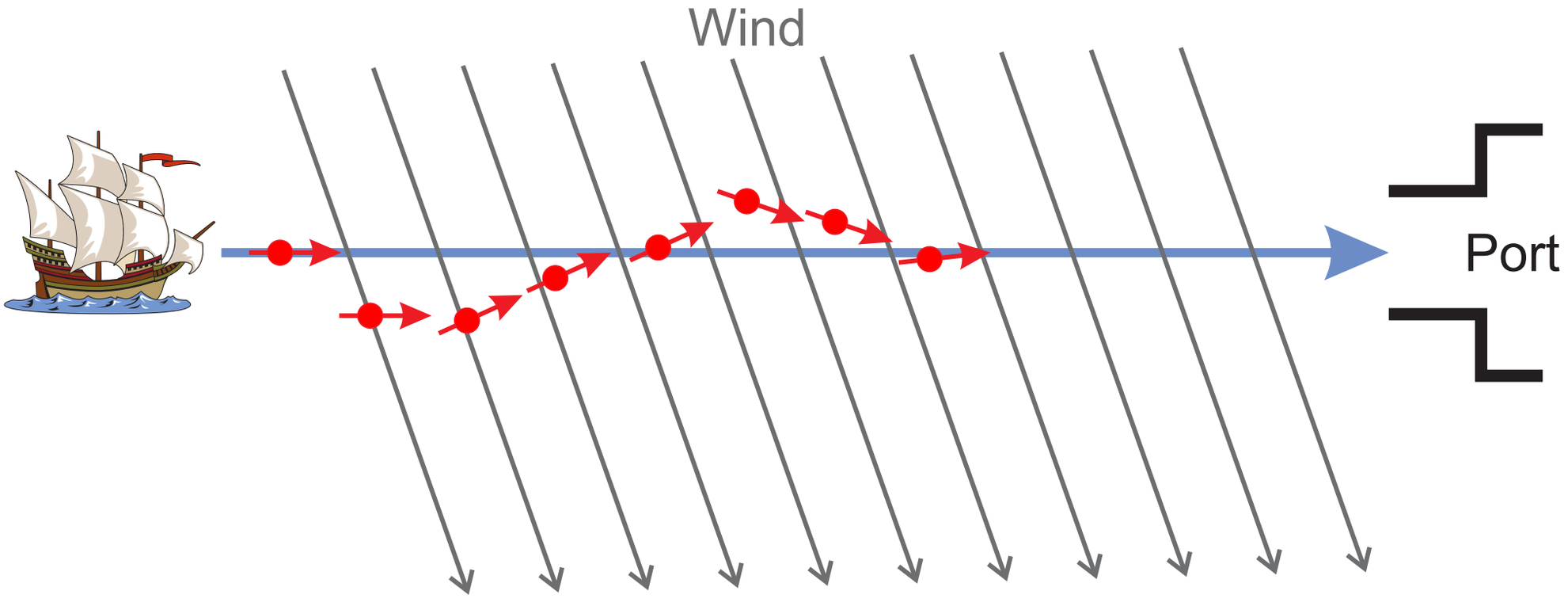

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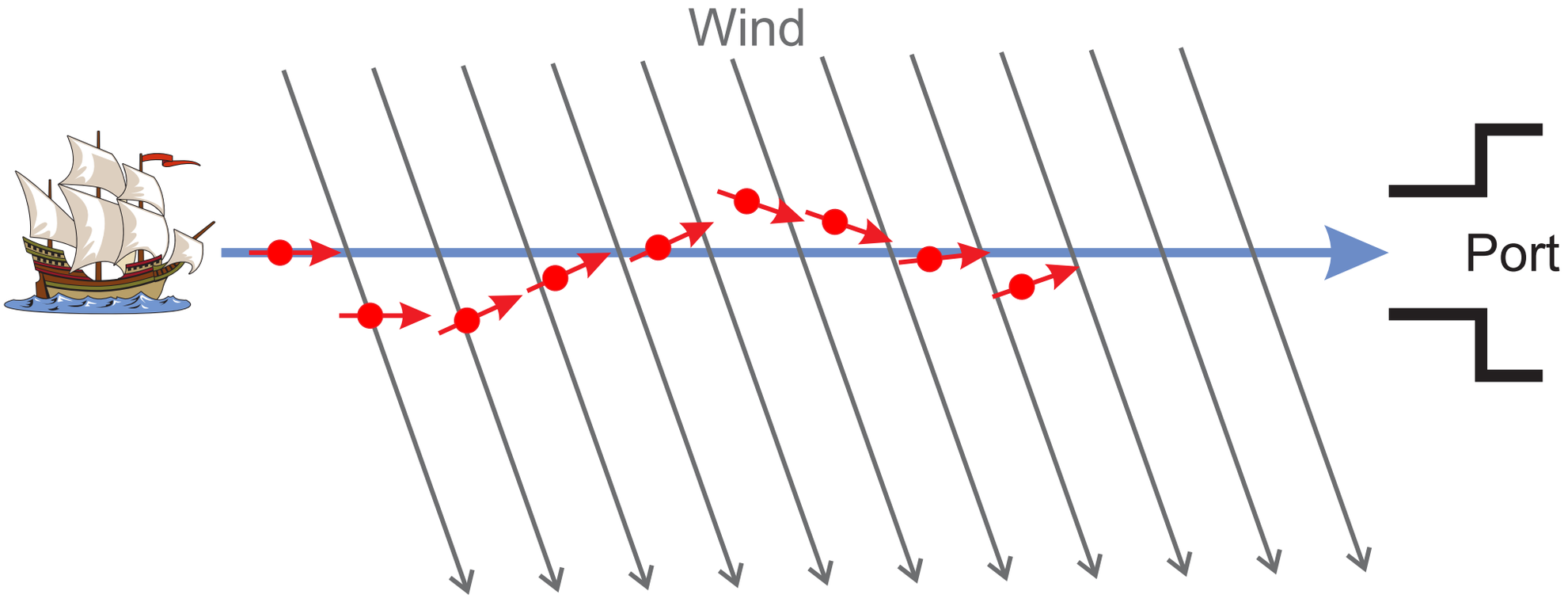

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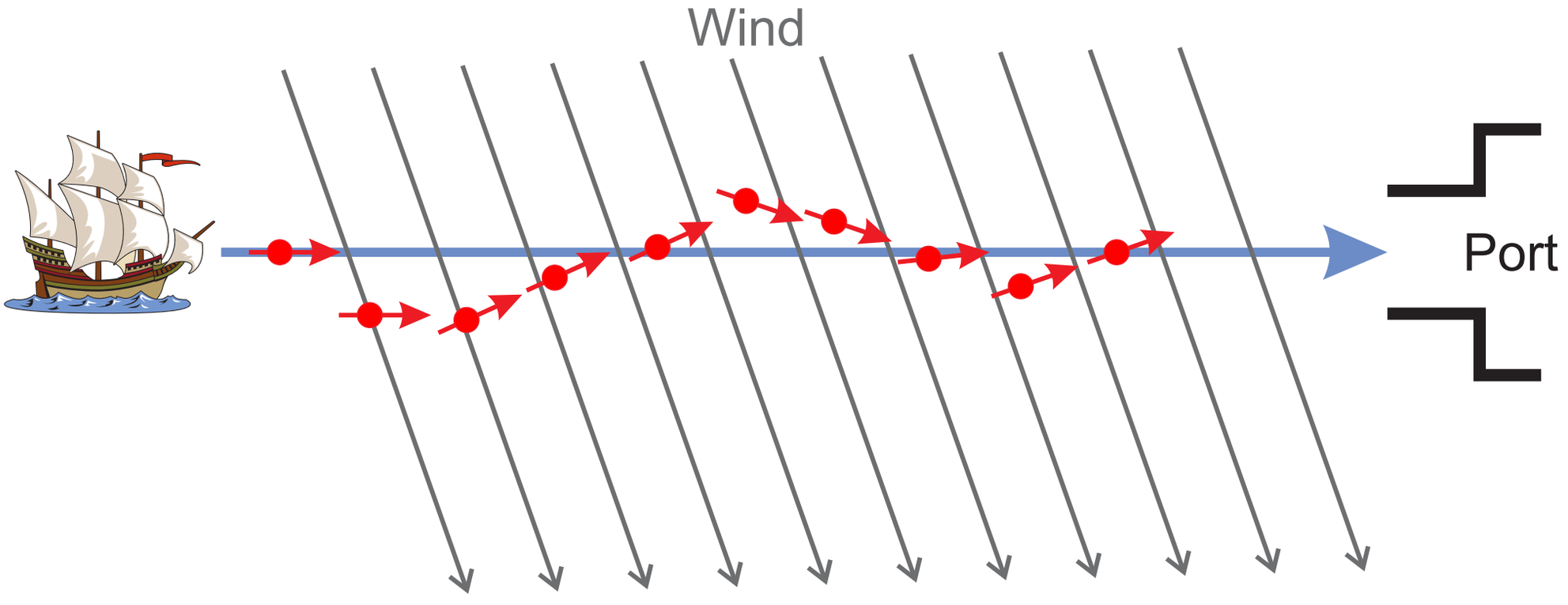

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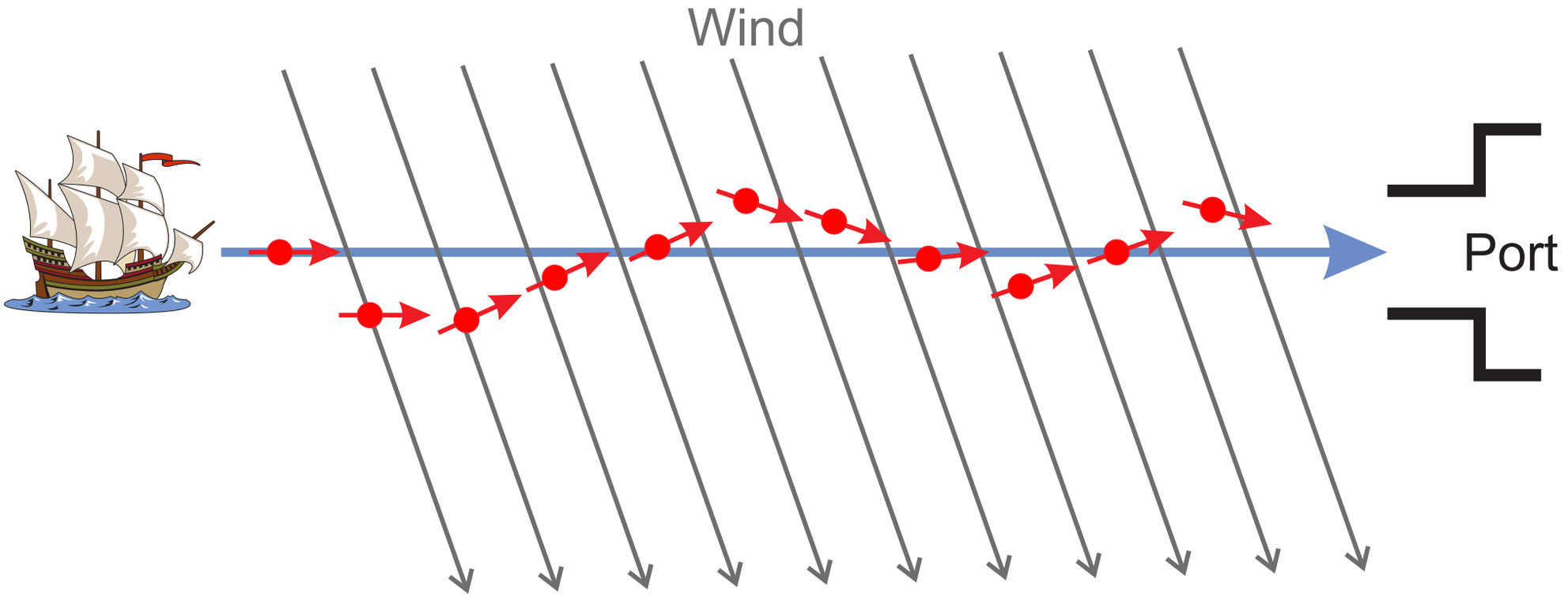

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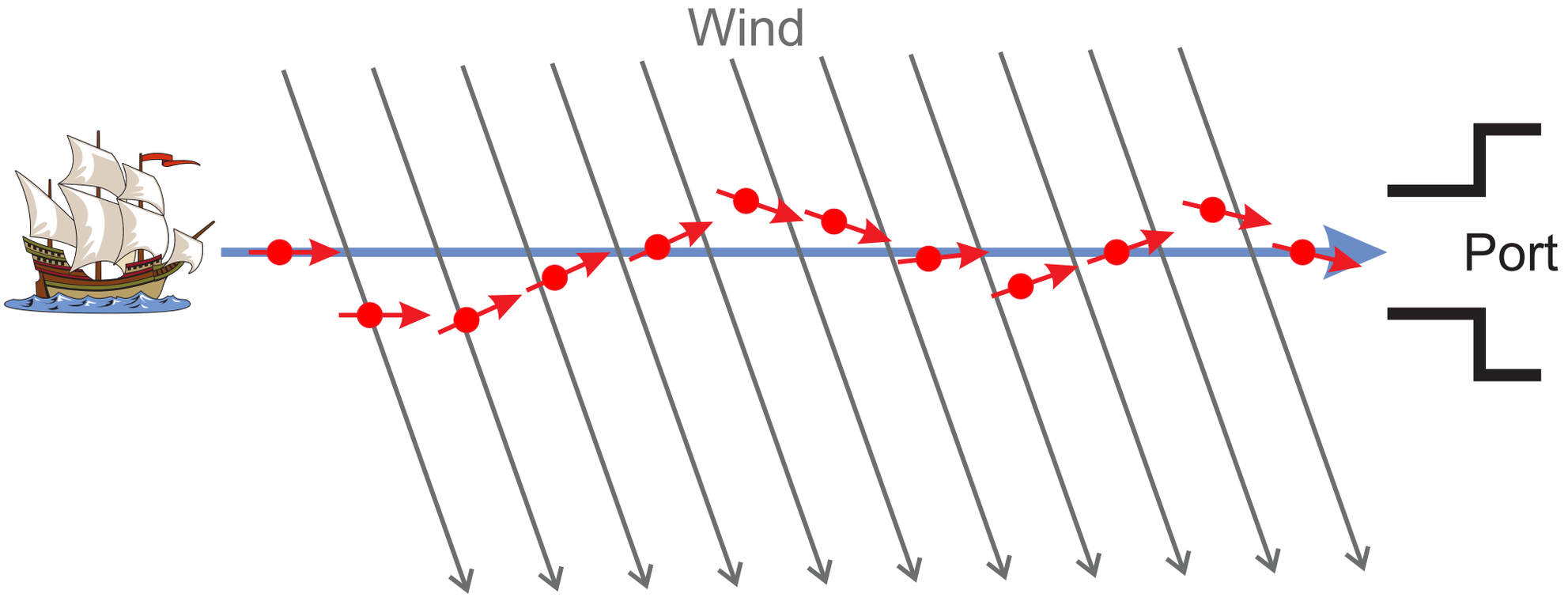

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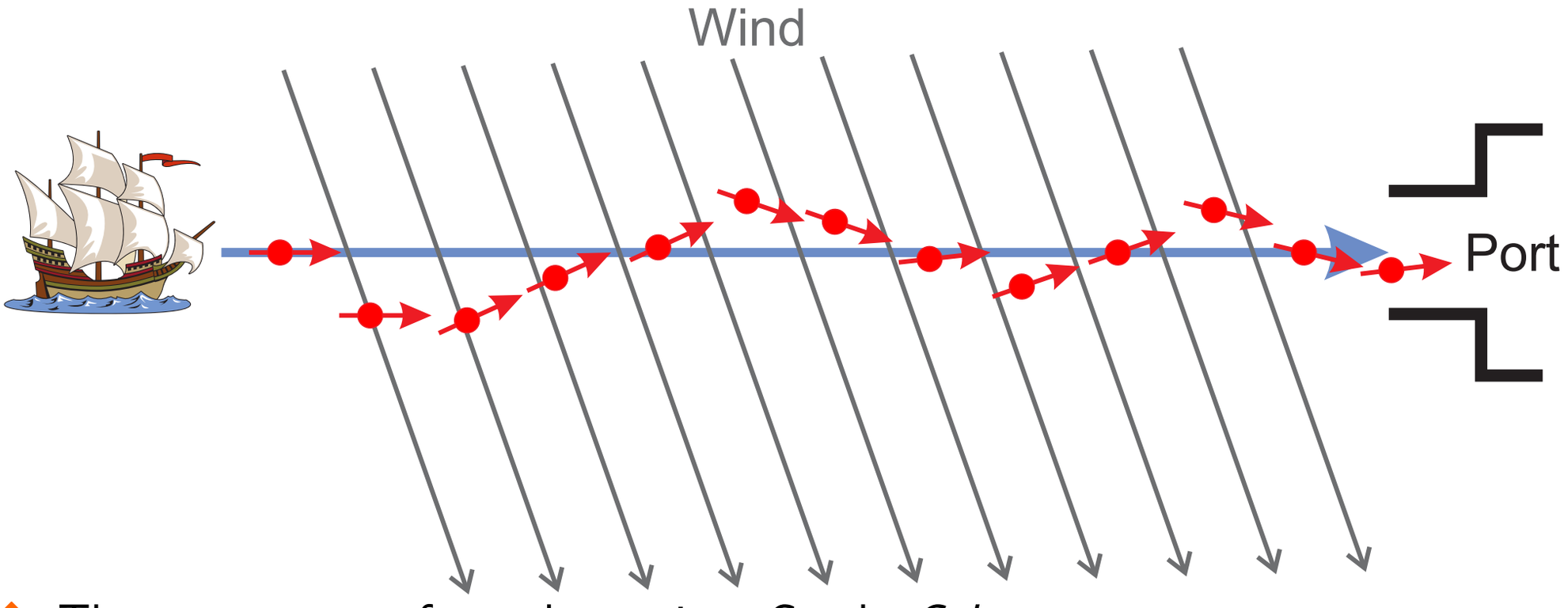
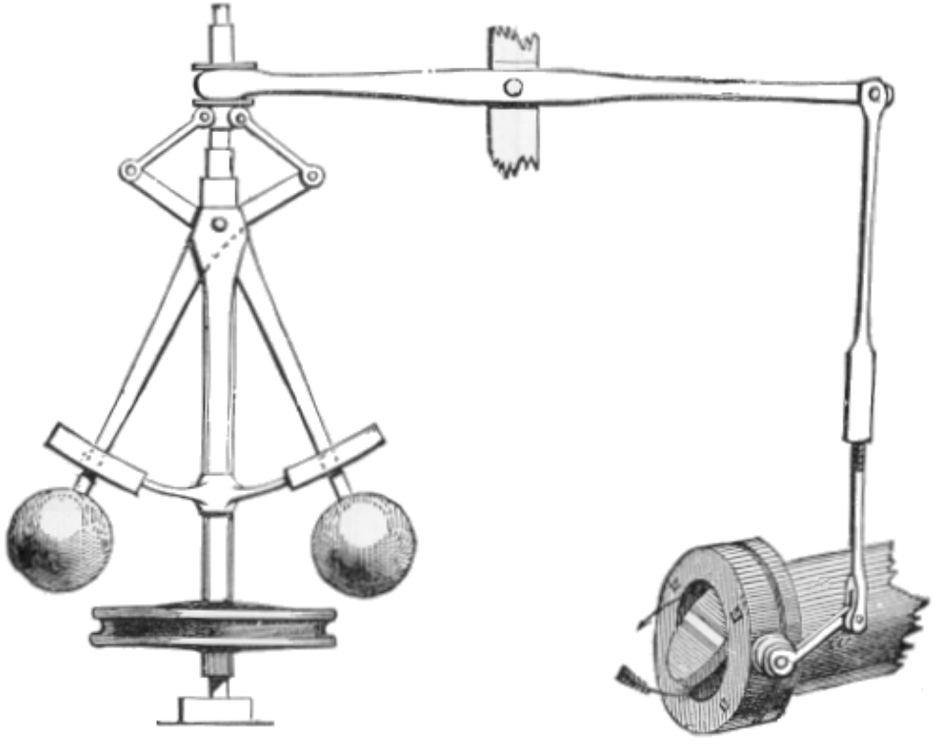
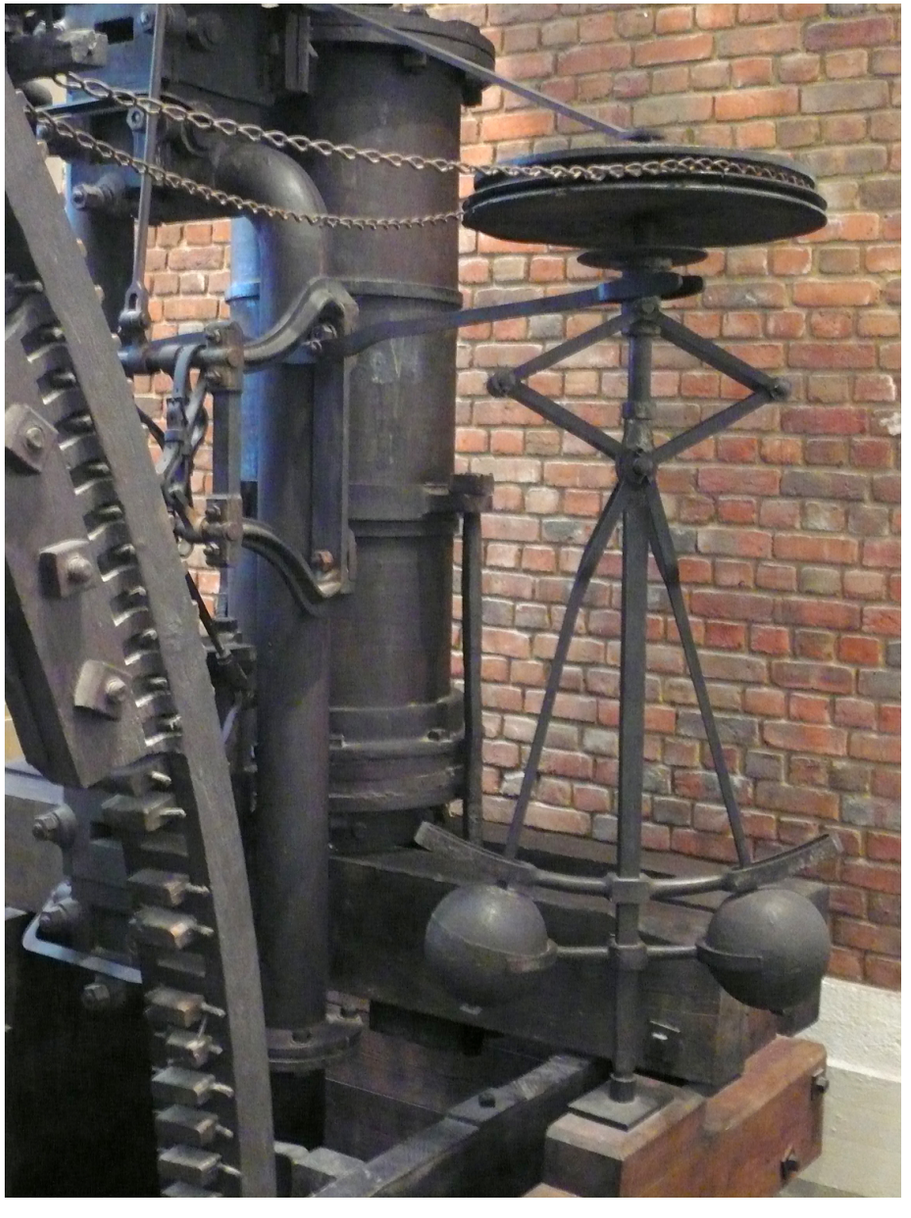


- The name comes from the ancient Greek. *Cybernetes* means steersman.
- Becomes *Governor in Latin*.
- The term *'cybernétique'* was used by French physicist André-Marie Ampère (1775–1836).

Centrifugal Governor





- Boulton & Watt engine of 1788, look at the picture $\rightarrow$
- J.C. Maxwell was the first who described the centrifugal governor mathematically.

Norbert Wiener, 1894-1964

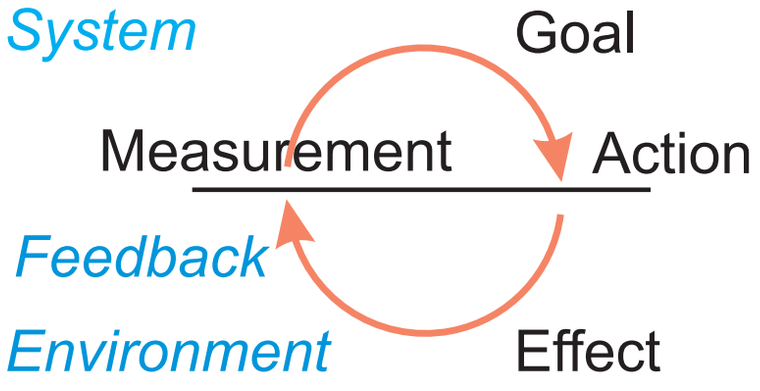
- His father Leo taught Slavic languages and German at Harvard University, was a friend of T.G. Masaryk.
- Norbert – a child prodigy. Bachelor in mathematics in 1909 at the age of 14.
- PhD from Harvard University in 1912 at the age of 17.
- His fame helped MIT to recruit a cognitive science team after WWII (psychology, mathematics, neurophysiology), including W.S. McCulloch and W. Pitts.
- Wiener filter, Cybernetics and many results in mathematics.
- Book: Cybernetics: Or Control and Communication in the Animal and the Machine. Paris, (Hermann & Cie) & Camb. Mass. (MIT Press), 1948.
- Autobiography:

  Ex-Prodigy: My Childhood and Youth. MIT Press, 1953

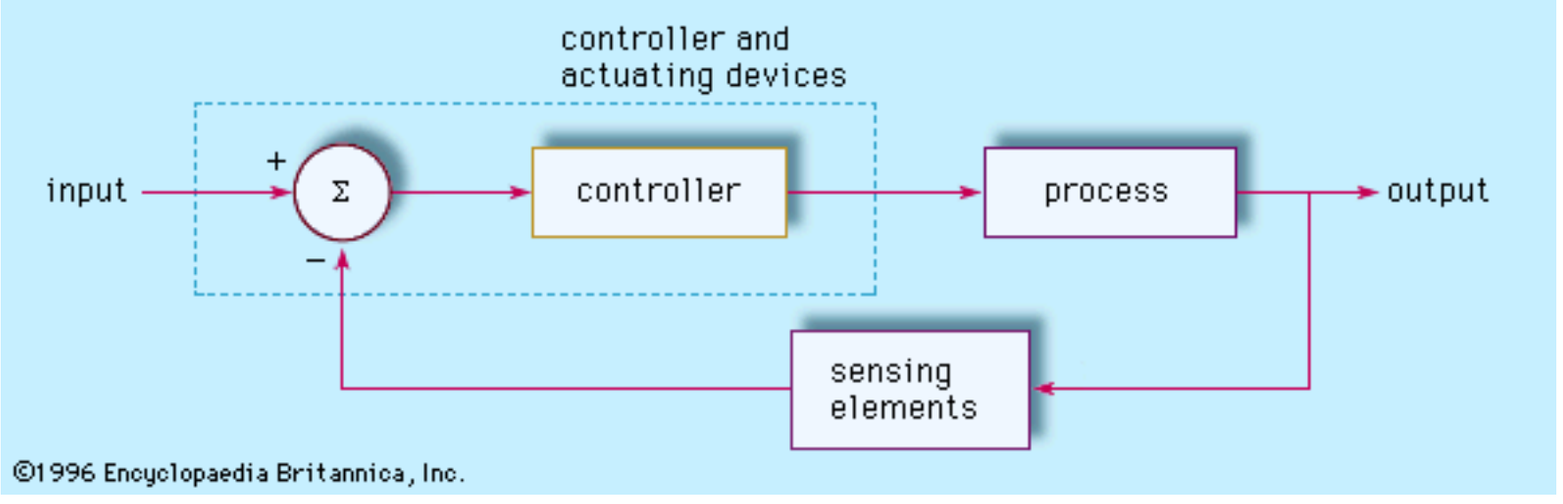
  I am a Mathematician. Gollancz, London, 1956. (the Czech translation exists: Můj život, Mladá Fronta 1970)

A cybernetics perspective, a system

- The system system has the goal.
- The system acts, aims toward the goal.
- The environment affects the system and indirectly the aiming to the goal (situatedness).
- Information returns to the system – the 'feedback'.
  - The system measures the difference between the current 'state' and the goal (error).
  - The system corrects the action to aim towards the goal.
  - This process is repeated.



A feedback control loop



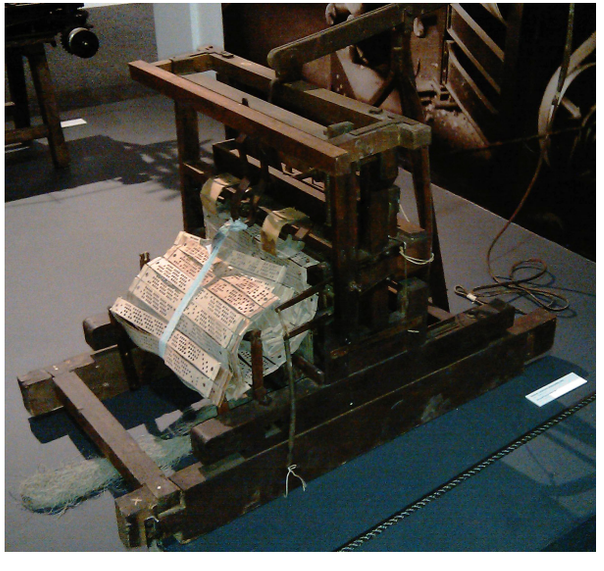
Benefits of the feedback:

- Reduces error (eliminates the error in some cases).
- Reduces sensitivity, enhances robustness, reduces uncertainty.
- Eliminates or removes disturbances.
- Improves the dynamic performance or adjusts the transient response.
- Allows stabilizing systems which are unstable otherwise.

Governing without feedback is possible too

Jackquard loom, example

- Invented by Joseph Marie Jacquard, first demonstrated in 1801.
- Revolutionized production of complex patterns on textiles.
- Programmable device by collection of punch cards.



1840, Museum Česká Skalice

Four most important principles of cybernetics (1)

- Feedback was intuitively used already in antiquity. Founders of cybernetics claimed that the feedback is a very general principle spanning technology, biology, astronomy, economics, etc.
- Information.
  - The first systematic description is by C. Shannon's entropy (1948). It says that information equals the amount of eliminated uncertainty which is described probabilistically.
  - The Kolmogorov-Solomonoff complexity (1966) length of the string ($\sim$ program) explaining the data, also called minimum description length principle.

Recommended reading for Czech students:
P. Vysoký: Padesát let kybernetiky, Od jednotného oboru logických pozitivistů k mnoha specializacím. Vesmír, Vol. 77, November 1998, pp. 626-633.

Four most important principles of cybernetics (2)

- Model.
  - The idea is that there are isomorphism between different systems, e.g., mechanical, hydraulic, electrical, which can be described by the same differential equations.
  - Modeling allows studying phenomena by thought experiments in different time, space scale or by physical experiments with realizable models.
- Law of Requisite Variety: "variety absorbs variety, defines the minimum number of states necessary for a controller to control a system of a given number of states." by W.R. Ashby (1903-1972), the English psychiatrist.

  This law can be applied for example to the number of bits necessary in a digital computer to produce a required description or model.

The Law of Requisite Variety

- Control is most fundamentally formulated as a reduction of variety: perturbations with high variety affect the system's internal state, which should be kept as close as possible to the goal state, and therefore exhibit a low variety.
- Control prevents the transmission of variety from environment to system.
- This is the opposite of information transmission, where the purpose is to maximally conserve variety.
- In response, Roger C. Conant 1970 "Good Regulator theorem": Every Good Regulator of a System Must be a Model of that System.

William R. Ashby
(1903-1972)

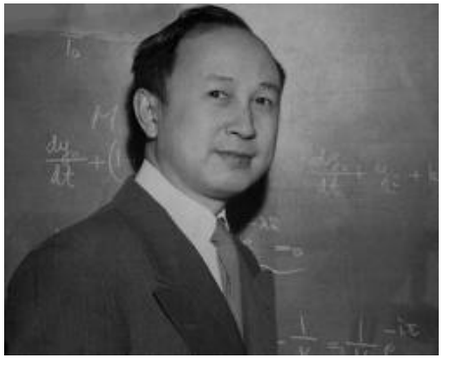
Scope of cybernetics (outside of technology)

- Explanation of communication = psychology.
- Modeling of learning = cognitive science.
- Limits of knowing = epistemology.
- Hearer makes the meaning = post-modernism.
- Reality as a social construction = constructivism.
- Reliable methodologies of describing = science.
- Measuring understanding & agreement
  = science of subjectivity,
  = second-order cybernetics.

Engineering cybernetics, Tsien Hsue-Shen (1)

- Another transcription of the name: Qian Xuesen (1911-2009).
- MSc. in Mechanical Engineering in China, 1935 left China to USA, MSc. from MIT 1936.
- PhD from Caltech under Theodore von Kármán in 1939, member of the 'Suicide squad' – built rockets with a colleague PhD student Frank Malina.
- Suicide squad was moved to Pasadena. Jet Propulsion Laboratory was created in 1943 there.

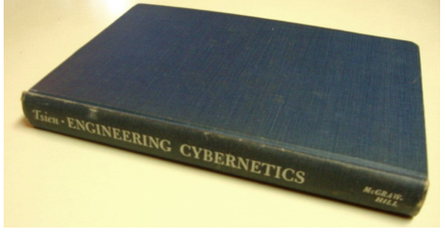
Frank Malina,
WAC Corporal Rocket, Oct 1945.



Tsien Hsue-Shen in 1939

Engineering cybernetics, Tsien Hsue-Shen (2)

- After the WWII, he investigated German scientists including Werner von Braun.
- His 800 pages report summarizing German results became the classified Bible of the US rocket and space programs.
- Became the first director of JPL in 1949.
- McCarthyism put him into hause arrest from 1950-1955. After, he left for China.
- He wrote the textbook: Engineering Cybernetics, McGraw-Hill 1954, 289 p.



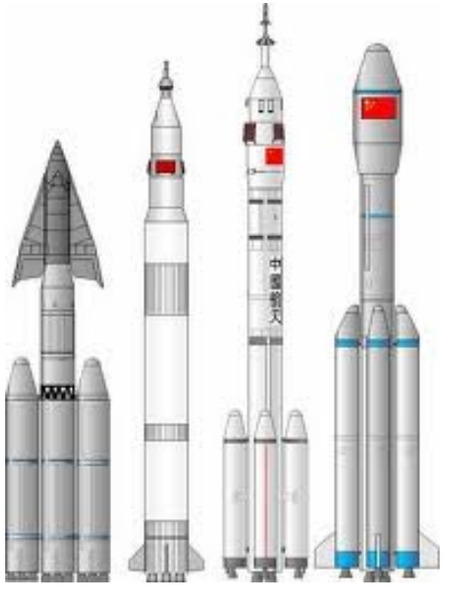
Ludwig Prandl, Tsien Hsue-Shen, T. von Kármán, 1945

Leaving USA 1955

Engineering cybernetics, Tsien Hsue-Shen (3)

- His book was warmly received in Eastern Europe and China.
- The book introduced a practical view on servomechanisms and their control.
- The book is a source of the discipline name "Technical Cybernetics" used in the East.
- Tsien became the father of the Chinese ballistic missile program as well as the Chinese space program.
- Someone noted when he was about to leave the USA that he is worth 2 army divisions. It was an obvious underestimate :-)

Tsien Hsue-Shen, with Mao, 1956



Tsien's Chinese Rockets

Cybernetics in the Soviet Union

- Under Stalin: Outlawed as bourgeois pseudoscience, "mechanistically equating processes in live nature, society and in technical systems, and thus standing against materialistic dialectics and modern scientific physiology developed by Ivan Pavlov".
- Arnošt (Ernst) Kolman (1892-1979), a Czech marxist philosopher with a cosmopolitan life, published the paper "What is cybernetics" in the Russian journal Voprosy Filosofii in 1955.
- Alexei Lyapunov (1911-1973) and Victor Glushkov (1923-1982), both pioneers of Soviet Computer Science, helped legitimation of Cybernetics in the Eastern Block.

A. Lyapunov promotes cybernetization.

Arnošt Kolman

Cybernetics in Czechoslovakia, two Zdeněk's

- Prof. Zdeněk Trnka (1912-1968) from the Czech Technical University in Prague started teaching servomechanisms in 1950s. He learned it in his post-war sabbatical in the USA.

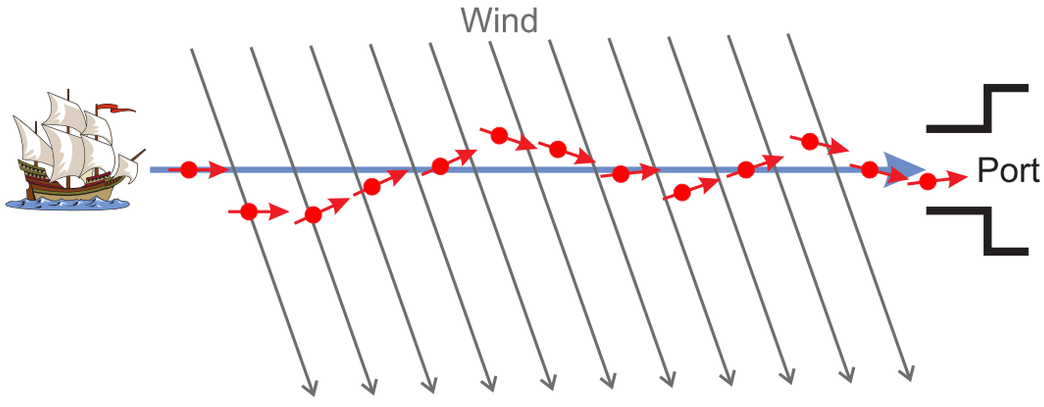
  He also helped to create a laboratory in the Czechoslovak Academy of Sciences which later transformed to the current Institute Information Theory and Automation (ÚTIA).

Zdeněk Trnka

- Prof. Zdeněk Kotek (1924-2004), the student of Zdeněk Trnka, led the cybernetics effort at the Czech Technical University in Prague for many years. He was the founder and the head of Department of Control Engineering in 1959-1989. His own research field was the non-linear control.

Zdeněk Kotek

Error and overshoot

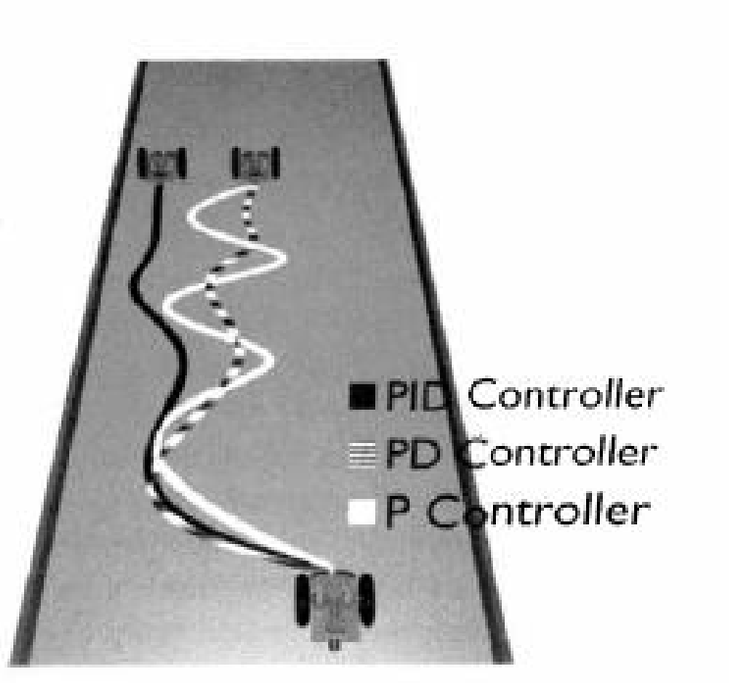


- Error: The difference in the current state and desired state of the system.
- Zero/non-zero error: Tells whether there is an error or not. The least information we could have.
- Direction of error: Which way to go to minimize the error
- Magnitude of error: The distance to the goal state.
- Overshoot:
  - The state goes beyond its set point (e.g., position) or changes direction before stabilizing on it.
  - Control is much easier if we know both magnitude and direction.

Controllers, oscillations, damping

Basic feedback controllers

- P: proportional control.
- PI: proportional integral control.
- PD: proportional derivative control.
- PID: proportional integral derivative control.



Feedbacks in a cognitive robot