A Brief History of Event-Based Control

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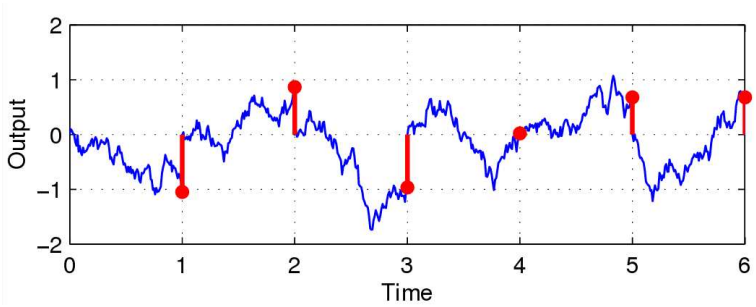
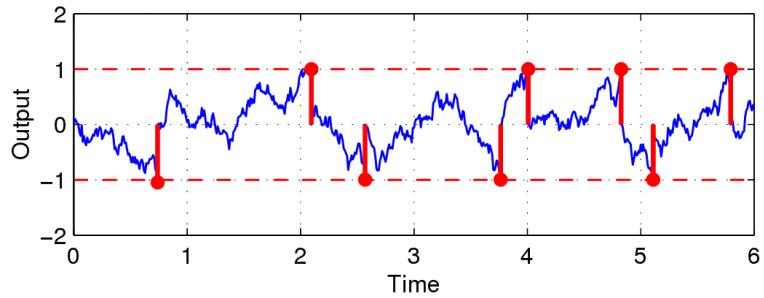
Concept of Event-Based

Example with impulse control [Åström & Bernhardsson, 1999]

Periodic Sampling

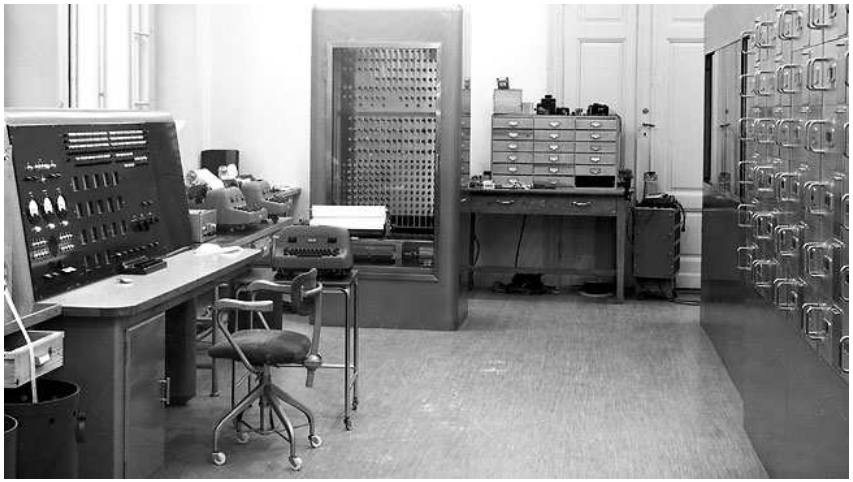


Event-Based Sampling



- **Event-Based:** Trigger sampling and actuation based on signal property, e.g $|x(t)| > \delta$ (*Lebesgue sampling*)
- A.k.a *aperiodic* or *asynchronous* sampling
- Potential for more efficient resource utilization
- Commonly found in biological systems, e.g neurons.

Rise of Digital Control and Periodic Sampling



BESK, 1953 [Tekniska Museets Arkiv]

- Idea of using computers for control emerged in the 1950's
- Periodic sampling matching the time-triggered operation of CPU
- With *stroboscopic model*, periodically sampled systems can be described by LTI difference equations - powerful and simple!
- Still, it has a hard time dealing with:
  - Multiple sampling rates and non-synchronized clocks
  - Sampling jitter

1959: First Idea of Event-Based Control

EXTENSION OF PHASE PLANE ANALYSIS

TO QUANTIZED SYSTEMS

Phillip H. Ellis

Countermeasures Division

Sperry Gyroscope Company

Division of Sperry Rand Corporation

Great Neck, L.I., New York

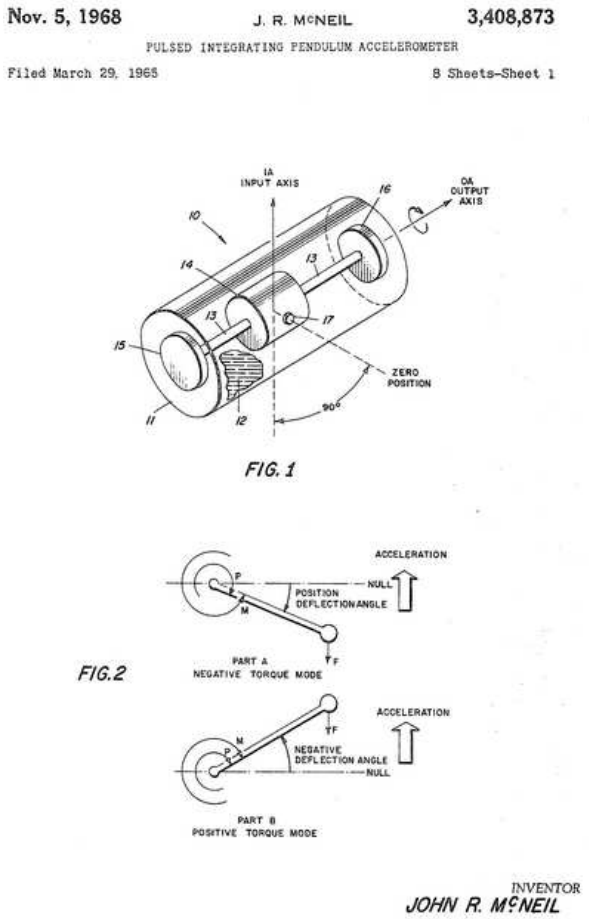
- By research engineer P.H Ellis at Sperry
- At the advent of digital control, considers synthesis with (coarsely) quantized input and outputs
- Lebesgue sampling, in essence

[...] Periodic sampling is not required. The most suitable sampling is by transmission of only significant data, as the new value obtained when the data are changed by a given increment. In certain cases, transmission of data by this means can be used to increase channel capacity. [...]

[Ellis, 1959]

1960's - 1970's: Adaptive Sampling

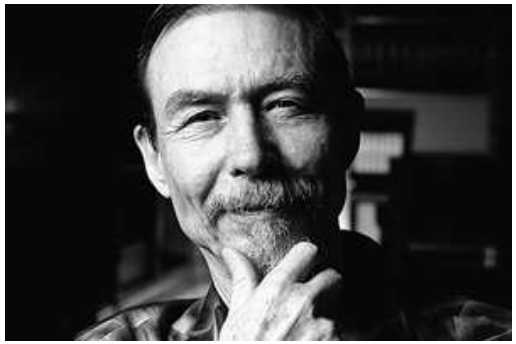
- Event-based paradigm in signal processing in 1960's. Gave rise to *asynchronous delta modulation*
- In control, *adaptive sampling* became a leading idea during 1960's and 70's
- Also, much work on accelerometers and gyros with event-based pulse feedback, e.g the Pulse Integrated Pendulous Accelerometer (PIPA)



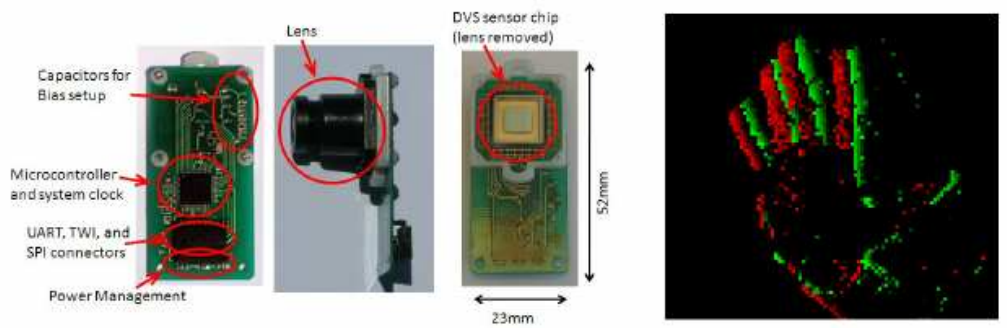
PIPA US Patent [McNeil, 1968]

1980's: Inspiration from Biology

- Carver Mead pioneering *neuromorphic engineering* after inspiration from biophycisist Max Delbrück.
- Developed biologically inspired electronic sensors with analog circuitry
- Asynchronous communication important in these systems
- Recent example: Dynamic Vision Sensor, an event-based camera



Carver Mead, 2002 [Wikipedia]



Dynamic Vision Sensor [Conradt et.al, 2014]

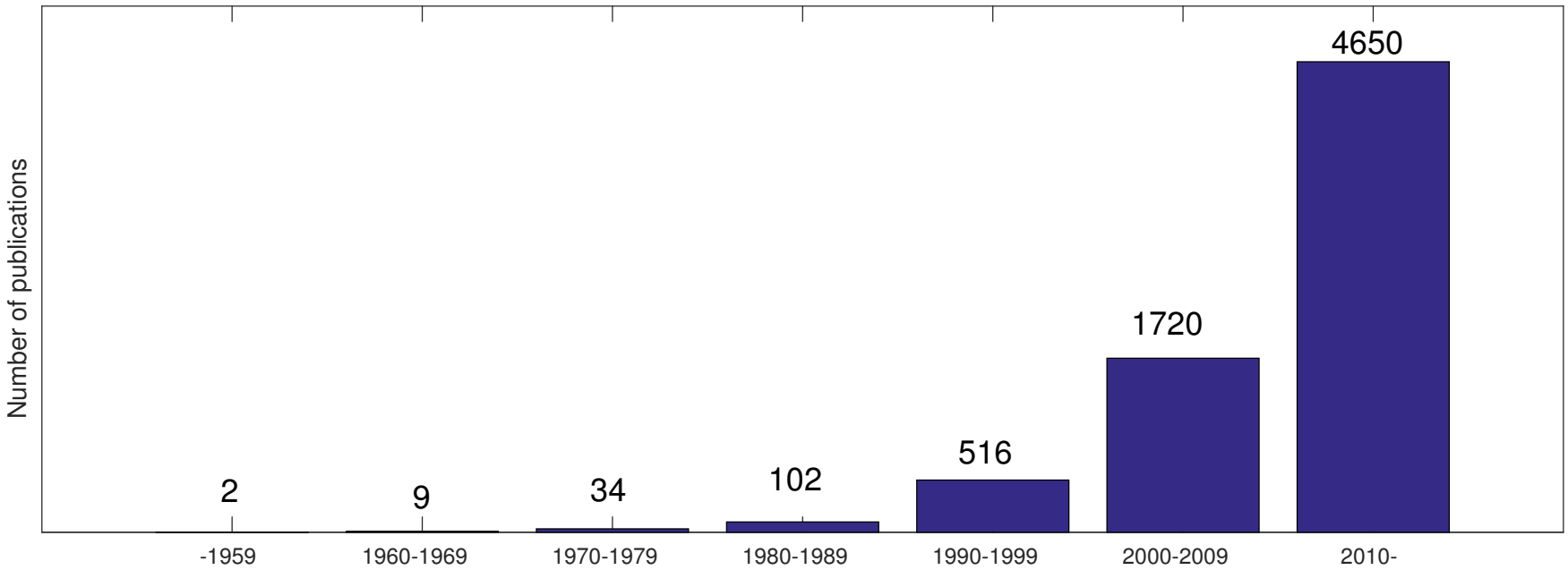
1999 and Onwards

Much of today's interest in event-based control sparked by 3 works:

- IFAC 1999: *Comparison of periodic and event based sampling for first-order stochastic systems* [Åström & Bernhardsson, 1999]
- IFAC 1999: *A simple event-based PID controller* [Årzén, 1999]
- Control Eng. Pract. 1999: *Asynchronous measurement and control: A case study on motor synchronization* [Heemels et.al, 1999]

Event-Based Control: Publications

Keywords: "event based control", "asynchronous sampling", "event triggered control", "aperiodic control"



[Google Scholar]

Today

- EBCCSP 15', 16'
- IFAC 2017: open invited session on event-based control.
- Many suggested alternatives to Lebesgue, e.g Kullback-Leibler divergence, variance-based triggering et.c
- Strong interest, but scattered results. Still no solid theoretical framework for analysis and design.
- Interesting neuromorphic sensors now available (e.g DVS, DYNAP)
- Interesting recent theoretical results on H_2-optimal event-based control by Leonid Mirkin.

Further Information

- M. Miskowicz, *Event-Based Control and Signal Processing*, CRC Press, 2016
- P.H Ellis, *Extension of phase plane analysis to quantized systems* Trans. on Autom. Cont., 1959
- K.J Åström & B. Bernhardsson, *Comparison of periodic and event based sampling for first-order stochastic systems*, IFAC, 1999
- K-E Årzén, *A simple event-based PID controller*,IFAC, 1999
- W.P.M.H Heemels et.al, *Asynchronous measurement and control: a case study on motor synchronization*, Control Eng. Pract. 1999
- DVS, DYNAP: `inilabs.com`