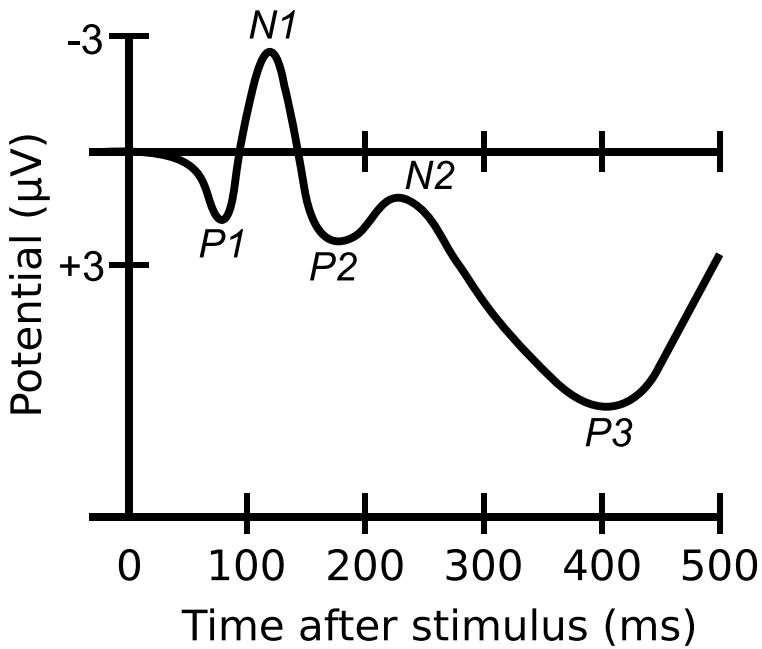
Event-Related Potentials in Brain-Computer Interfacing

Jeremy Hill

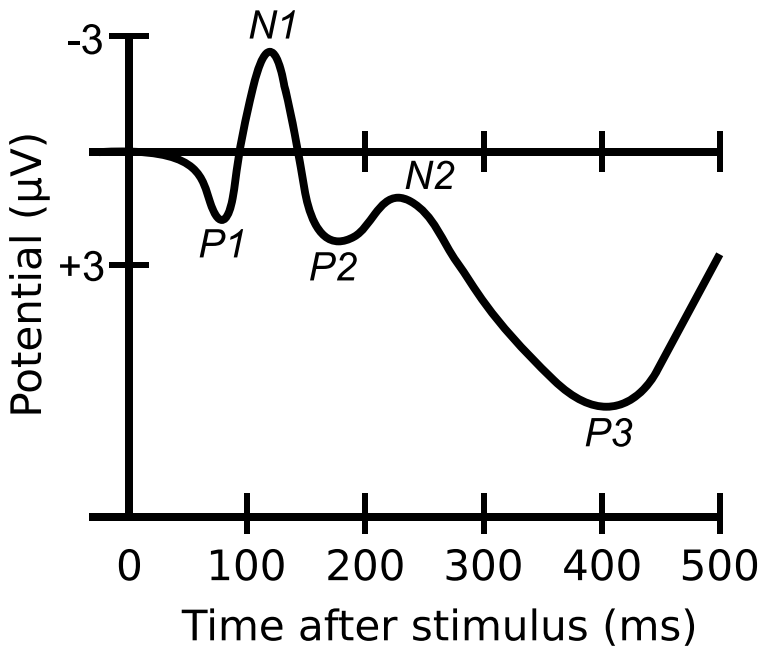
Max Planck Institute for Biological Cybernetics
Tübingen, Germany

Event-Related Potentials



schematic figure from
http://en.wikipedia.org/wiki/Event_related_potential

Event-Related Potentials



- N for negative, P for positive (beware: negative is sometimes plotted upwards, sometimes downwards).
- Numbered sequentially (P1, P2, P3, ...) or by typical latency in milliseconds (N140, P300, ...).

schematic figure from
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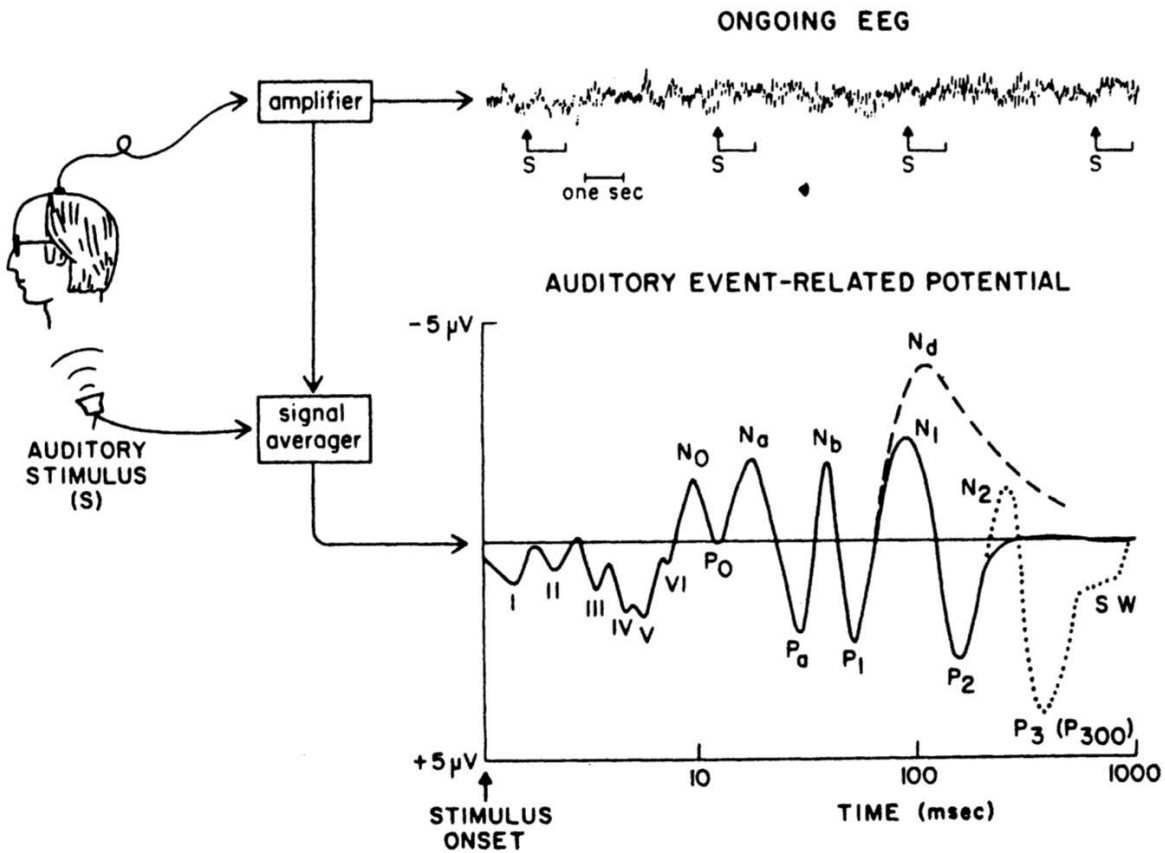

figure from Hillyard & Kutas (1983)
Annual Review of Psychology.

Event-Related Potentials

The EEG signal is a function of time *and* space. The positivity or negativity of a particular ERP peak depends on which electrode you measure.

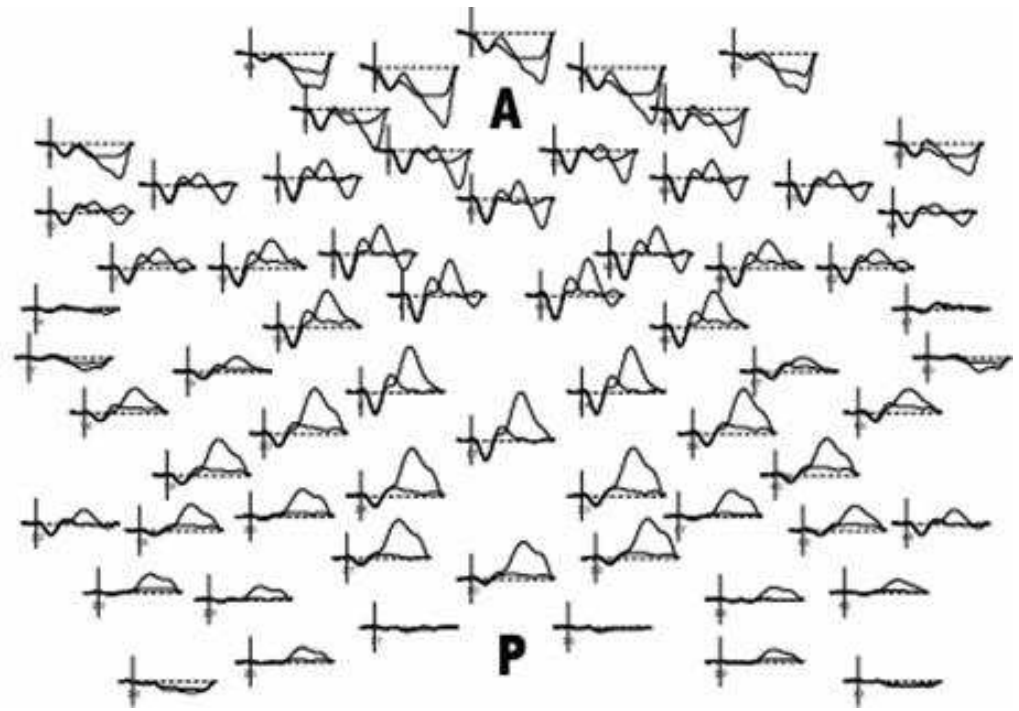

figure from Patel & Azzam (2005)
Int. J. Medical Sciences.

More Than Just Evoked Potentials

"Event-related potential" (ERP) is a newer term than "evoked potential" (EP), intended to be more general, and open to connotations of the brain's *active* role in processing stimuli.

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  The student forced to complete the assignment passed.

  vs

  The student forced the door open.
  The student tried to complete the assignment.

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Sounds promising for BCI application: P300 appears to encode both the information content of stimulus changes, and their relevance to the observer.

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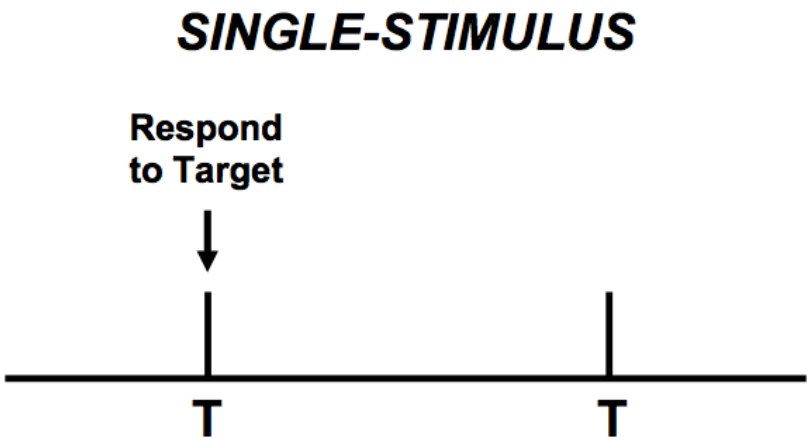
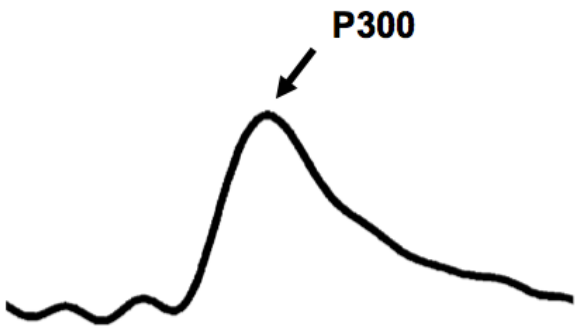
Today, authors are still more likely to refer to event-related potentials when they are talking about correlates of higher-level (more "cognitive") stimulus processing, and to evoked potentials when they are assuming their phenomena reflect lower-level (earlier, more "sensory") processing.

figures from Polich (2007)
Clinical Neurophysiology





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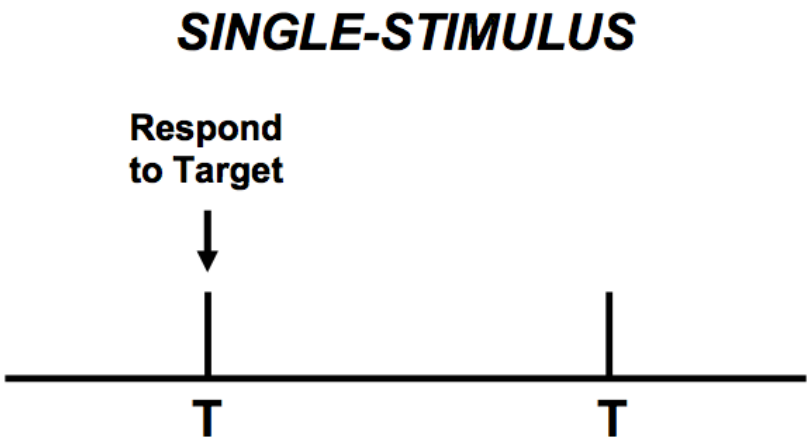

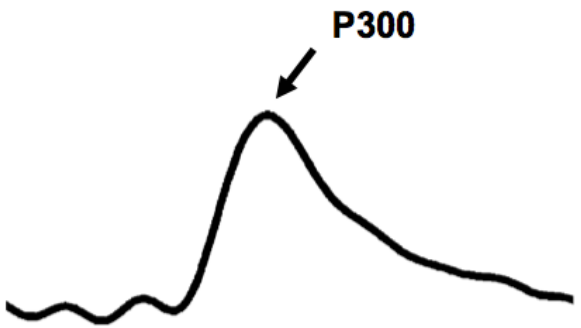

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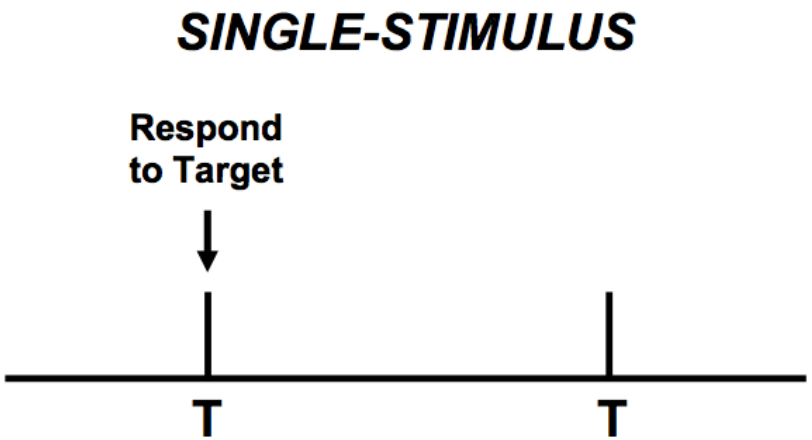

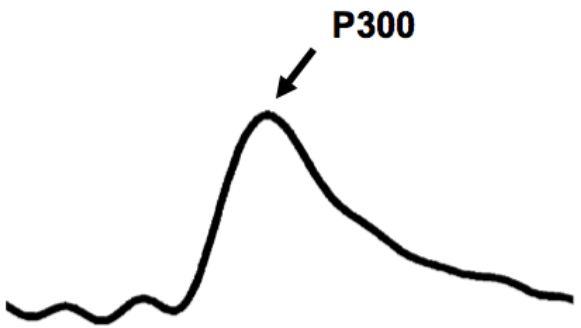

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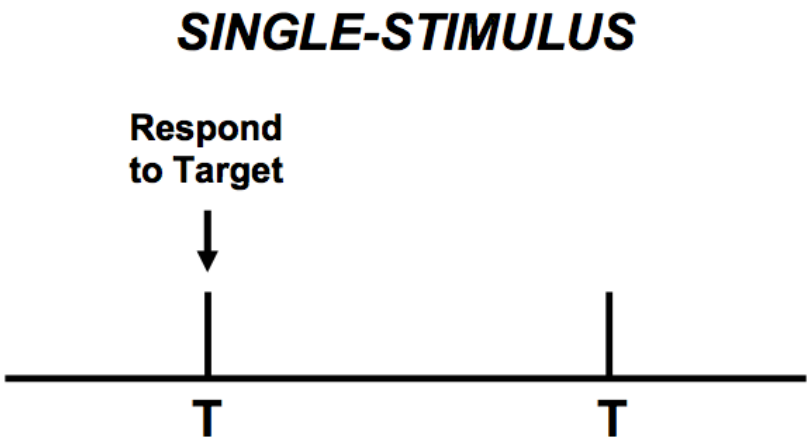

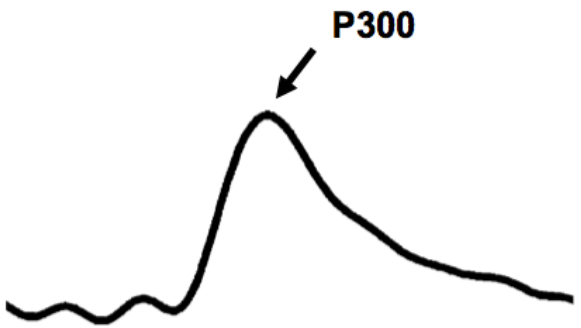

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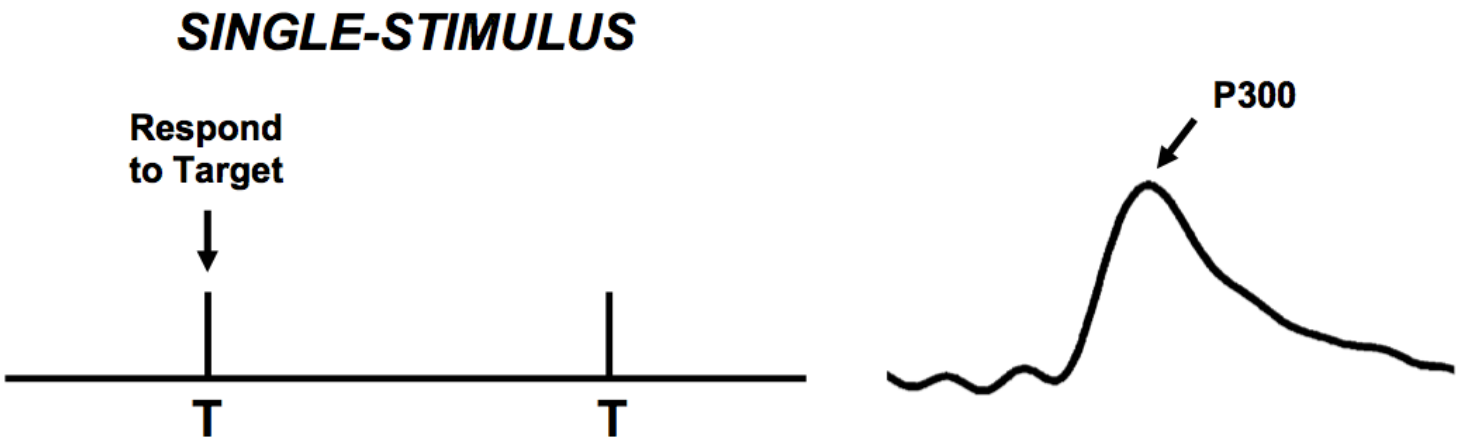

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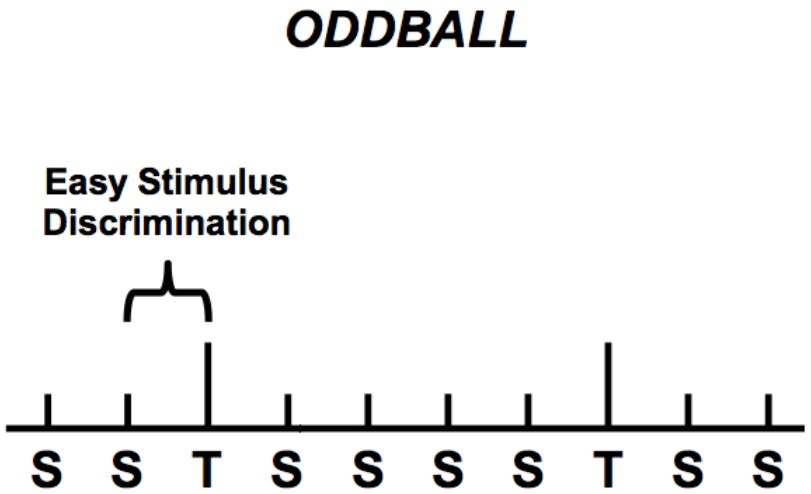

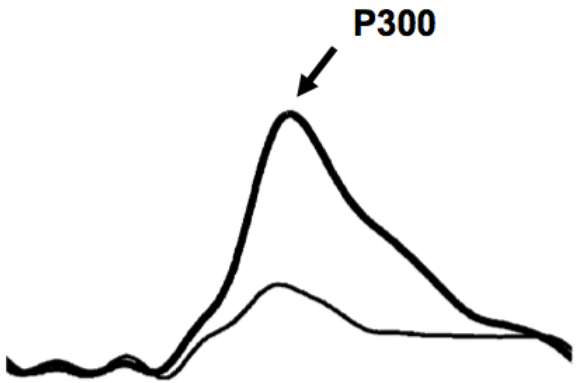

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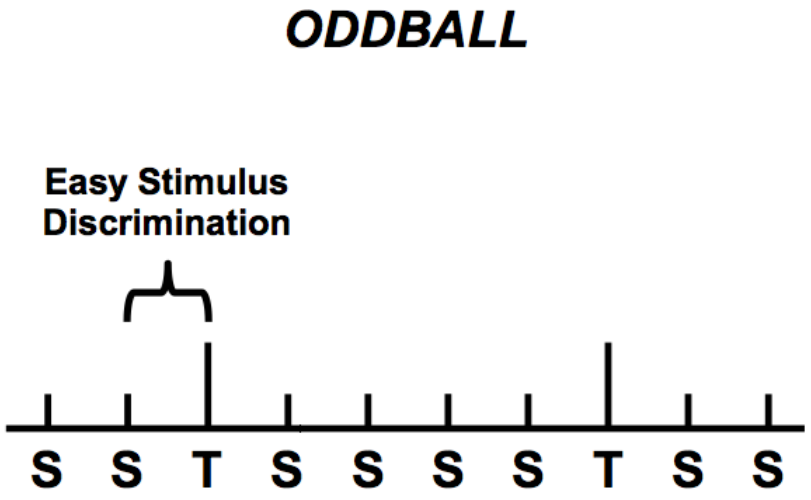

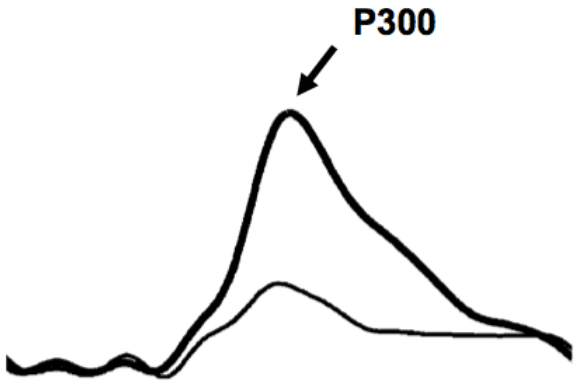

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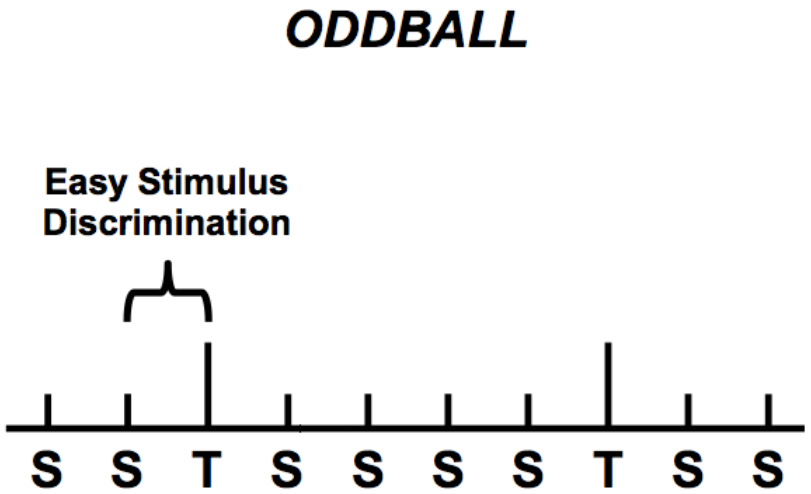

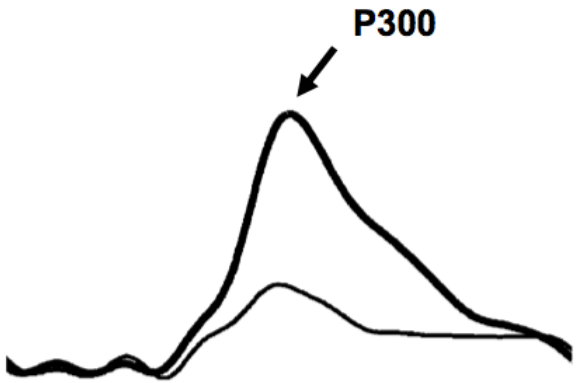

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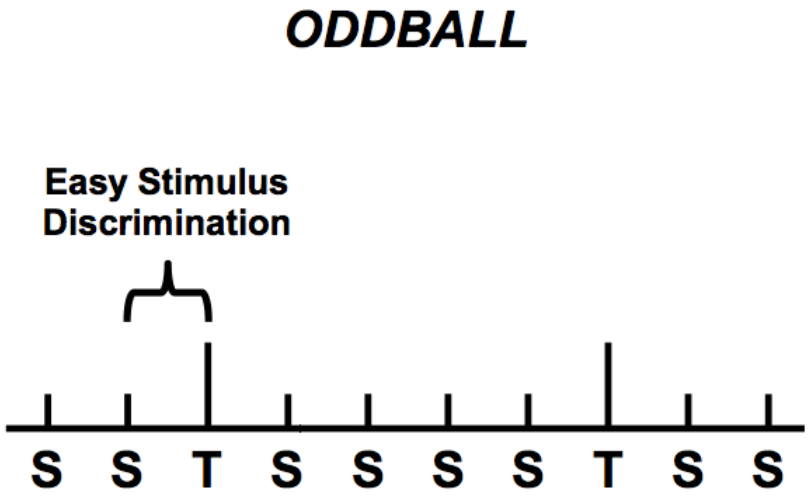

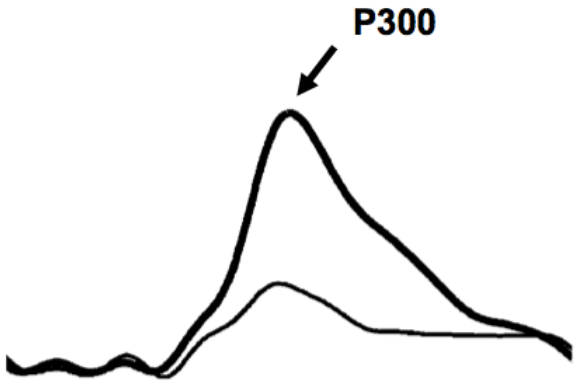

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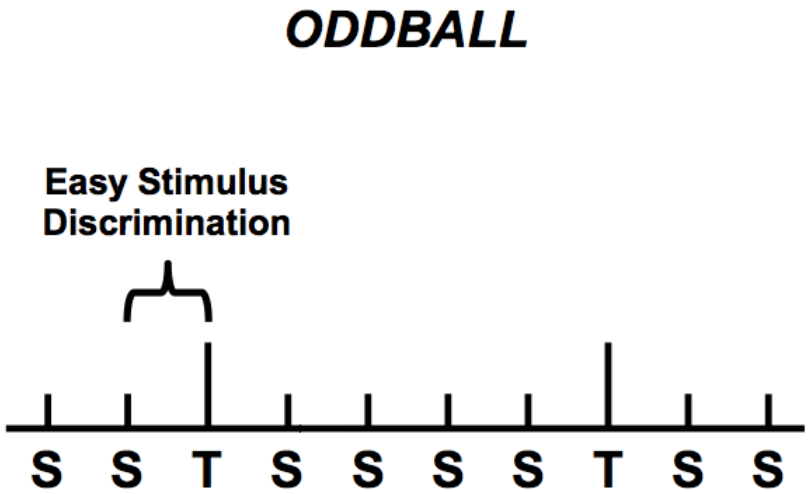

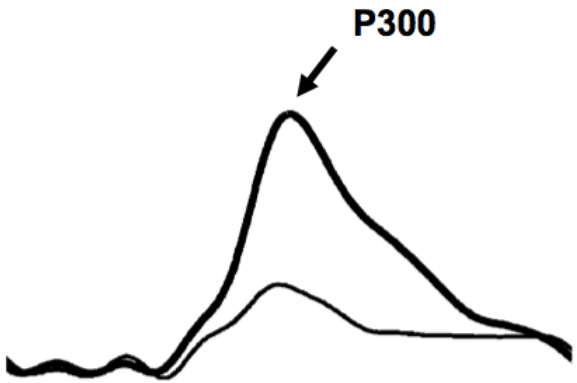

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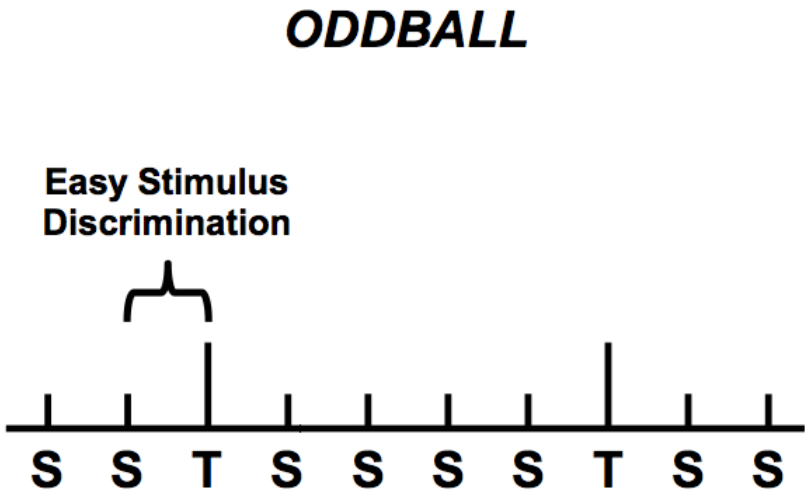

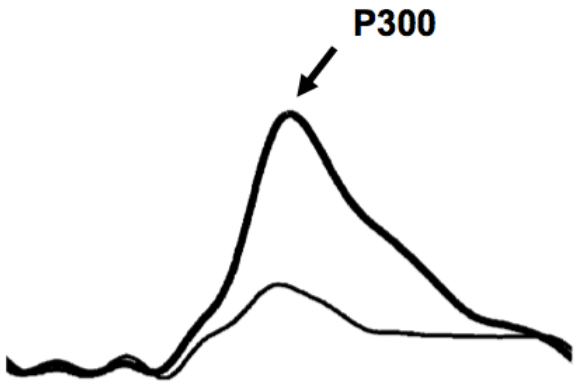

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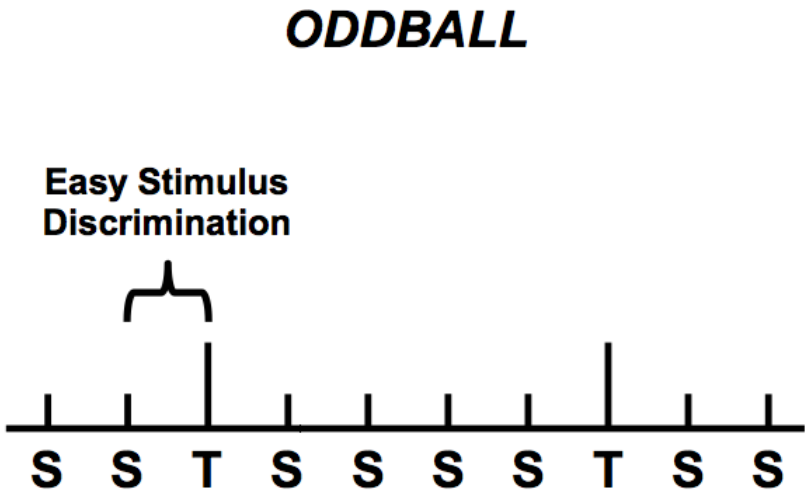

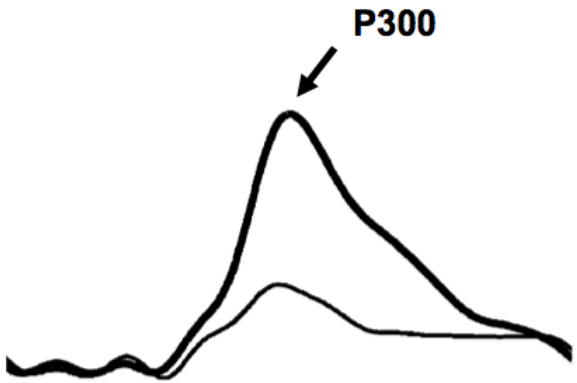

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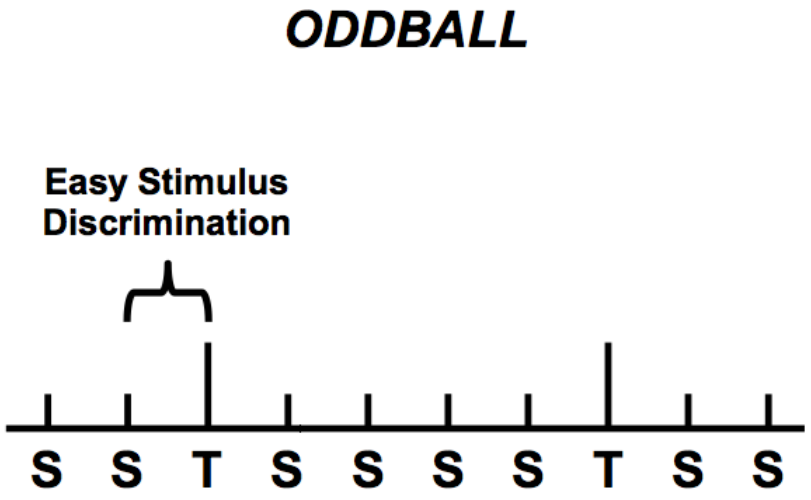

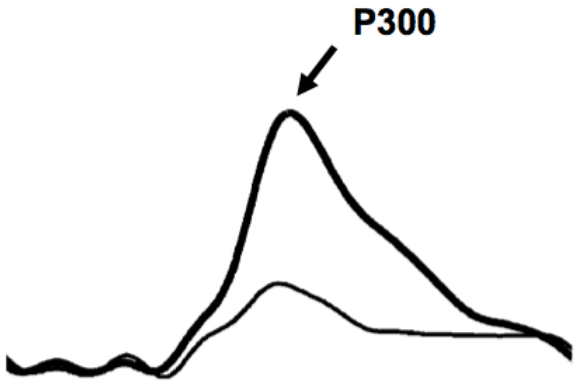

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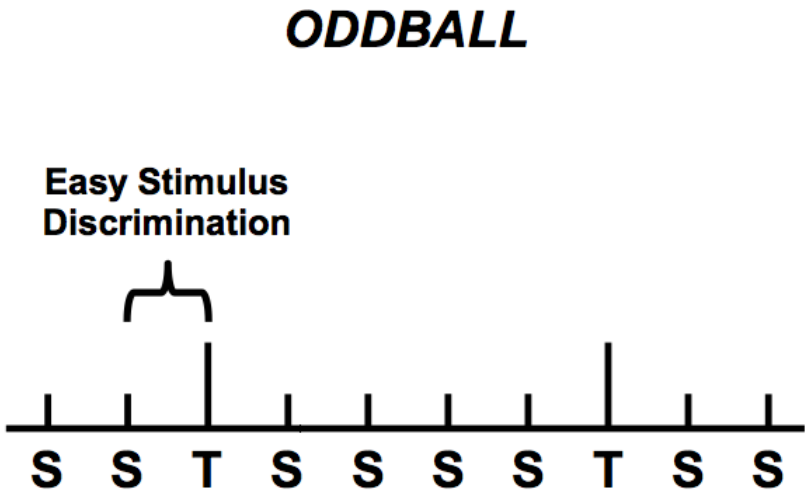

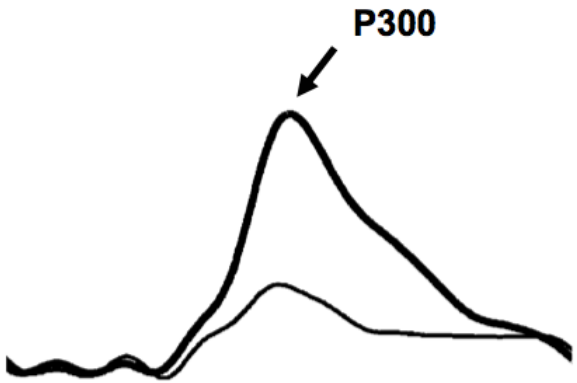

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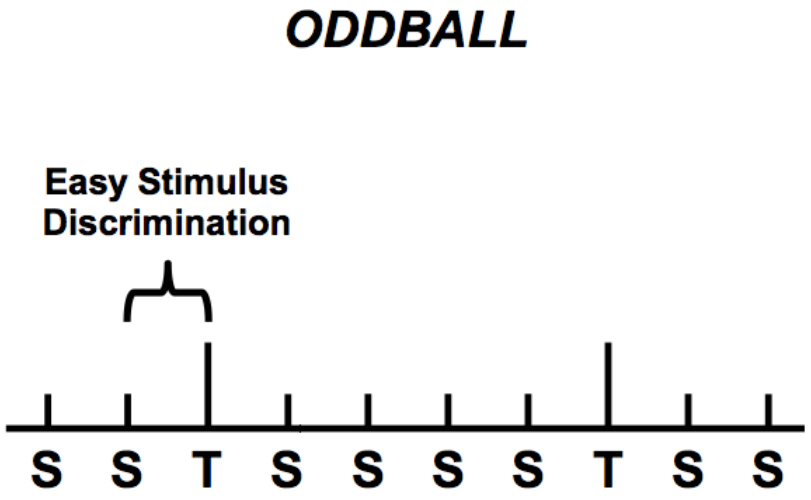

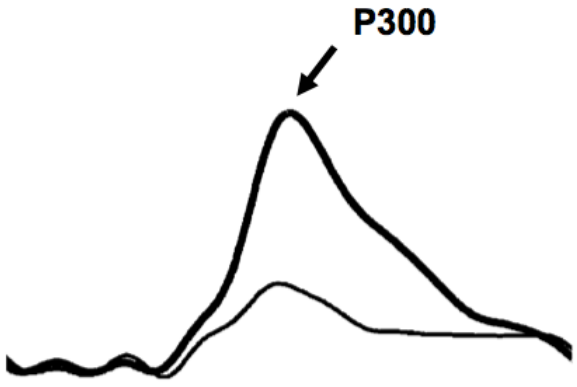

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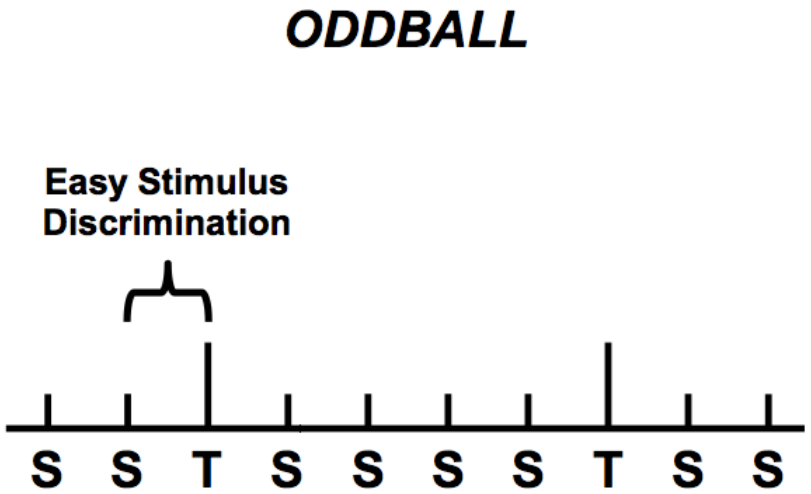

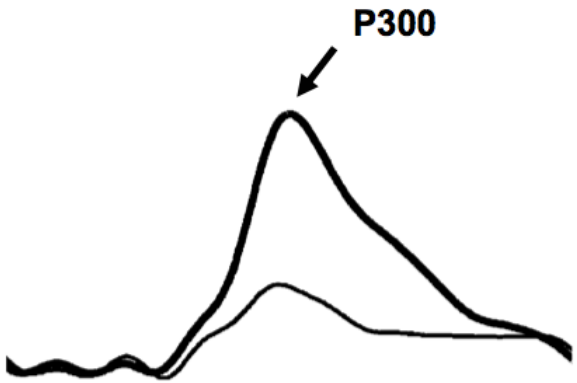

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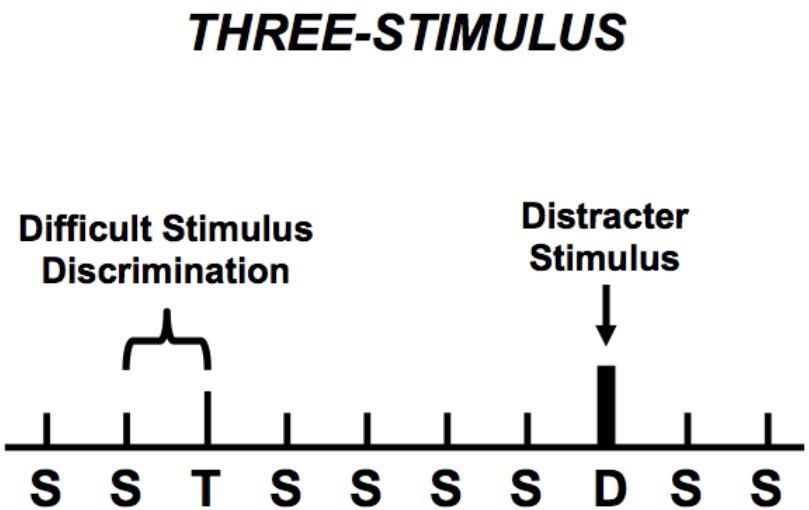

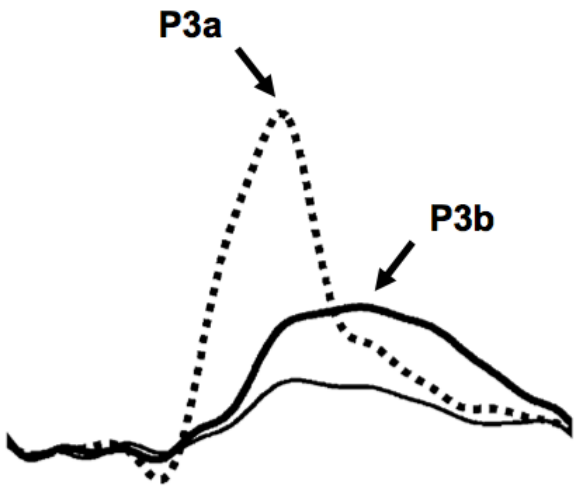

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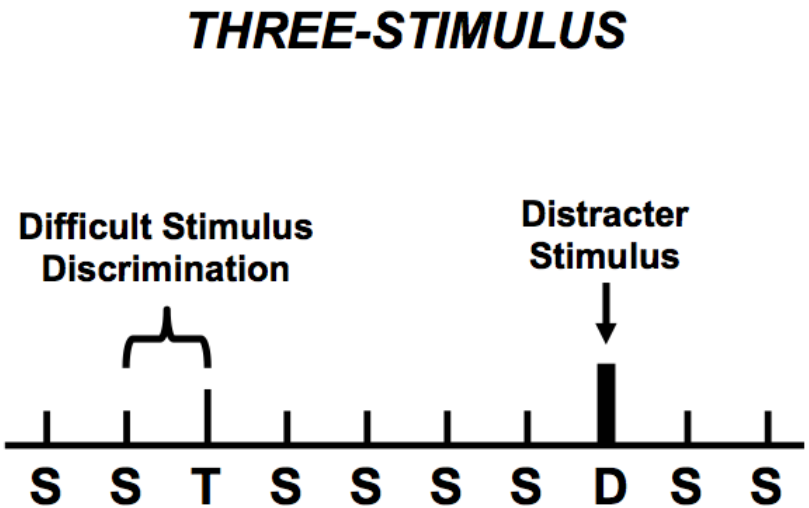

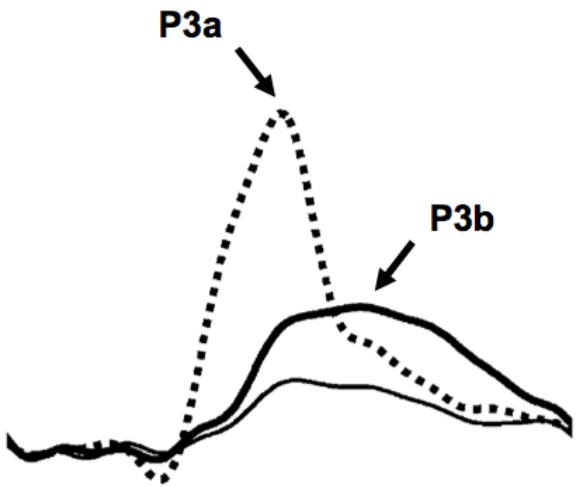

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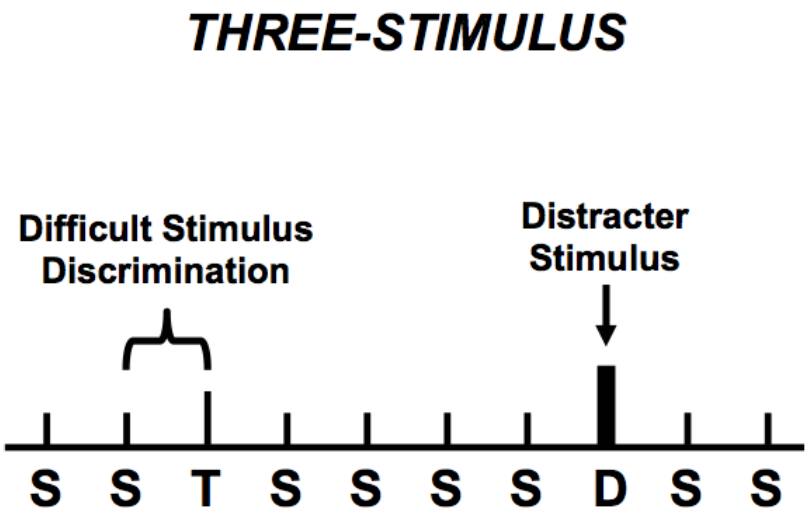

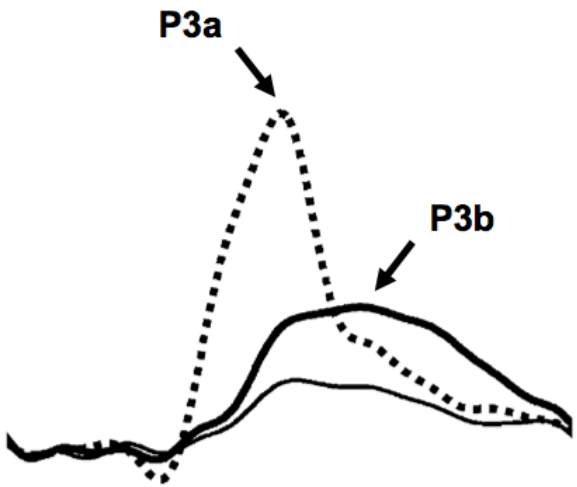

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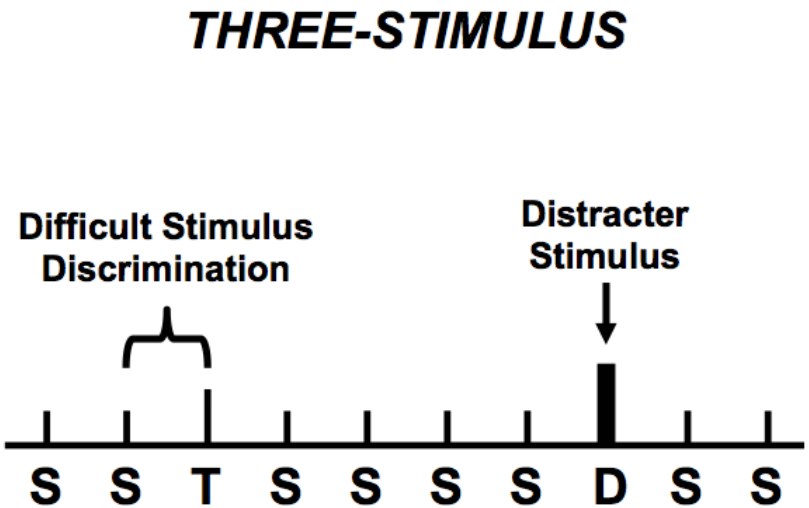

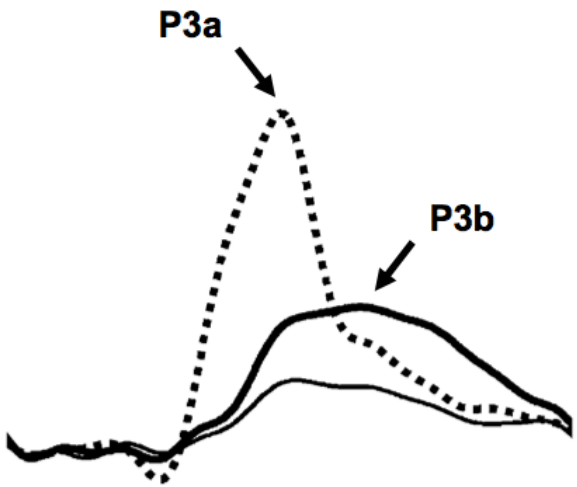

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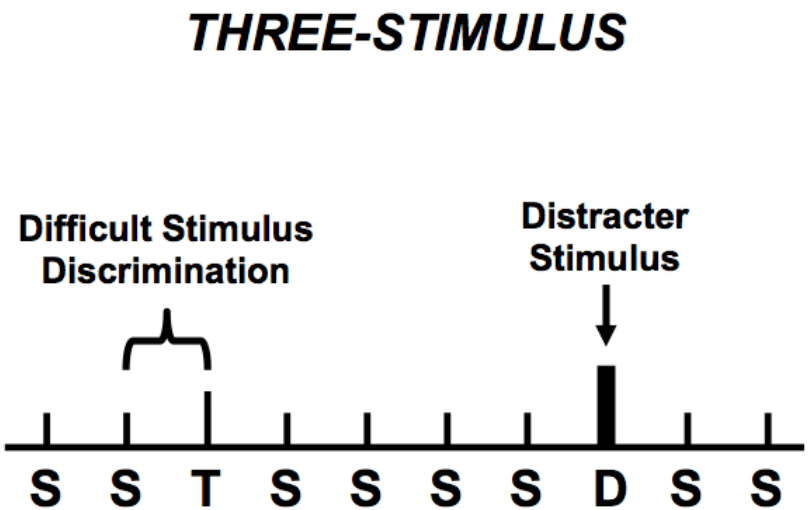

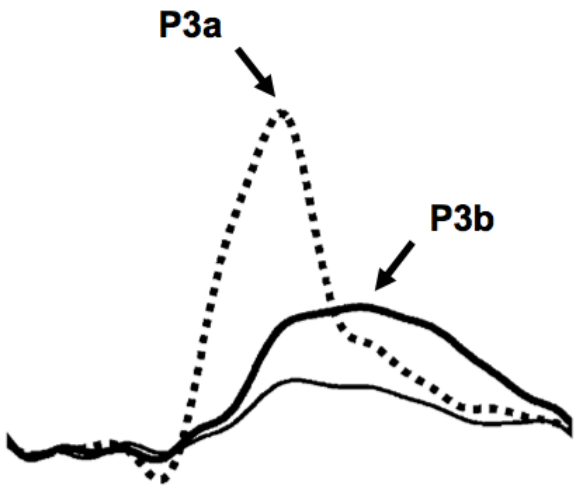

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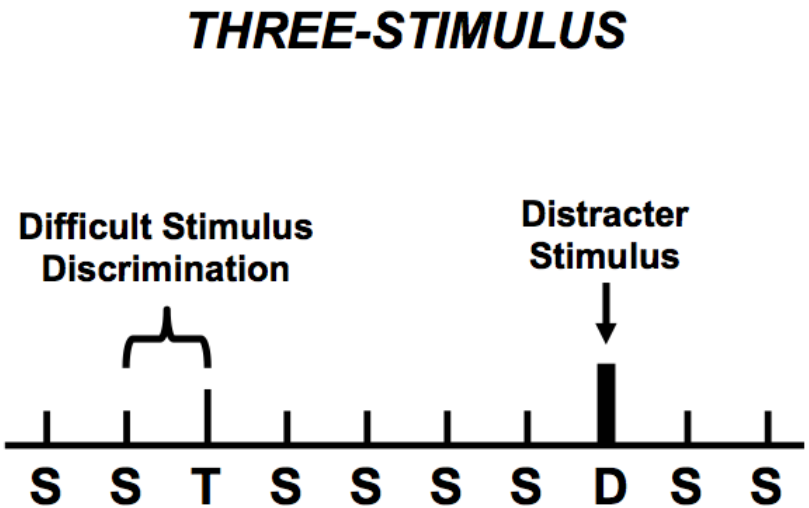

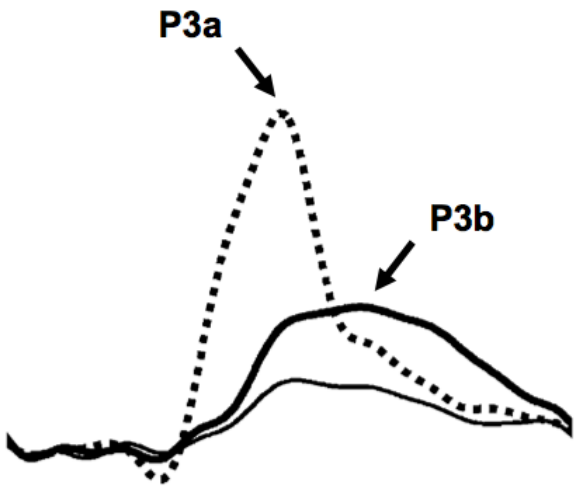

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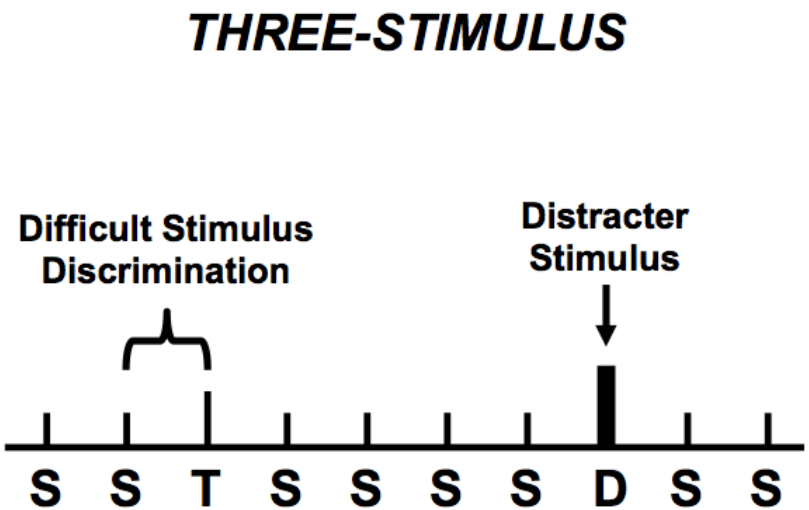

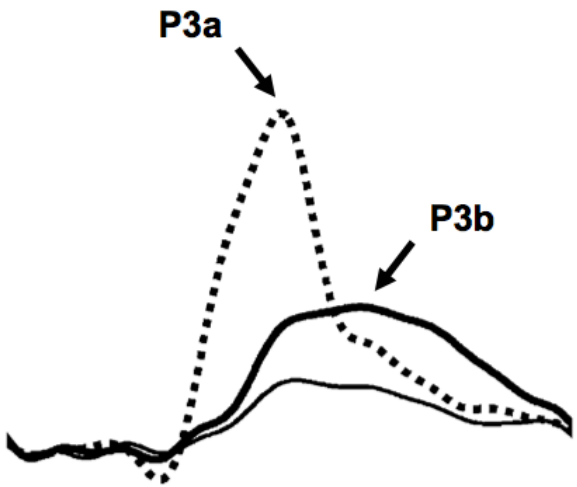

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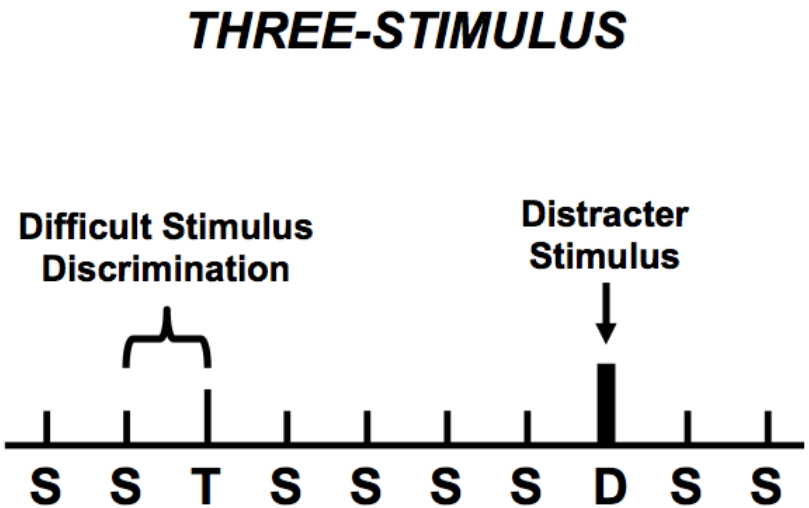

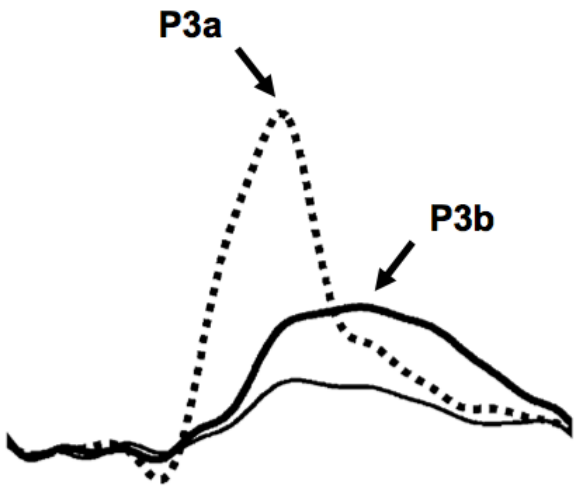

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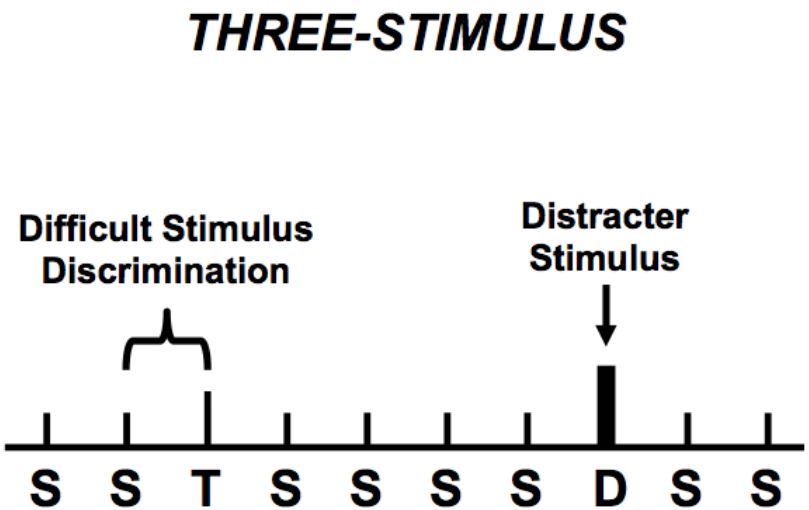

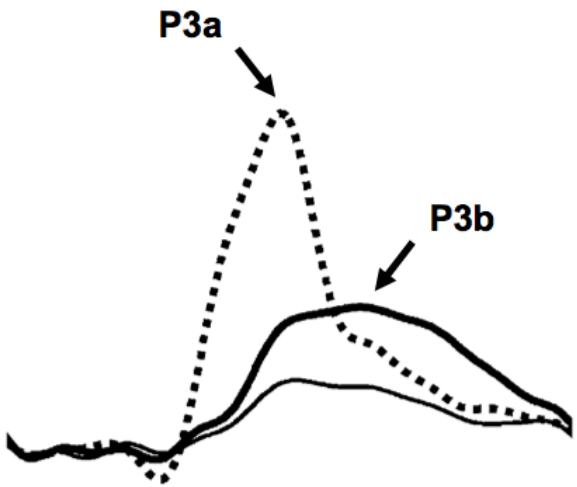

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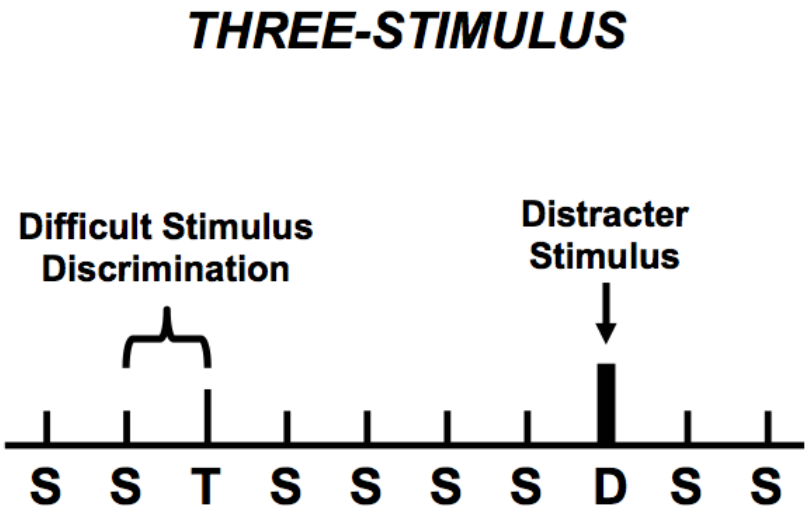

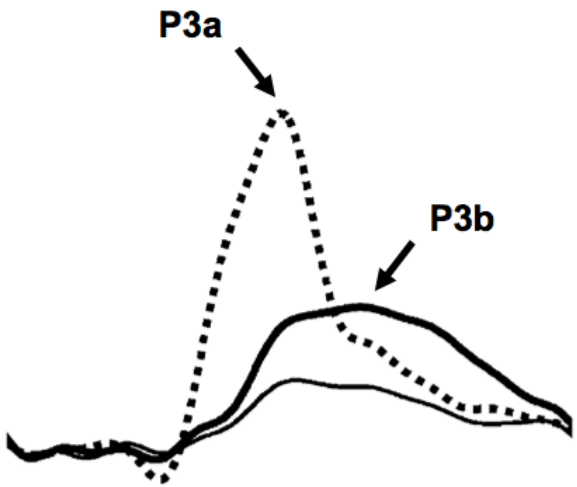

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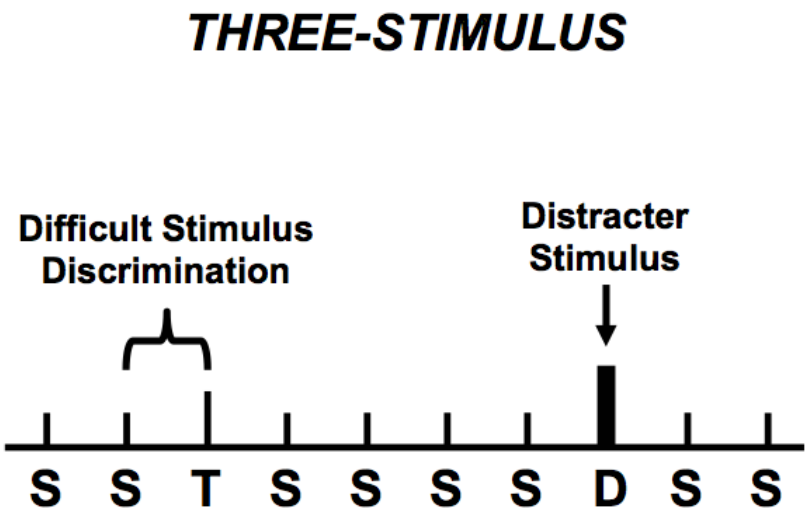

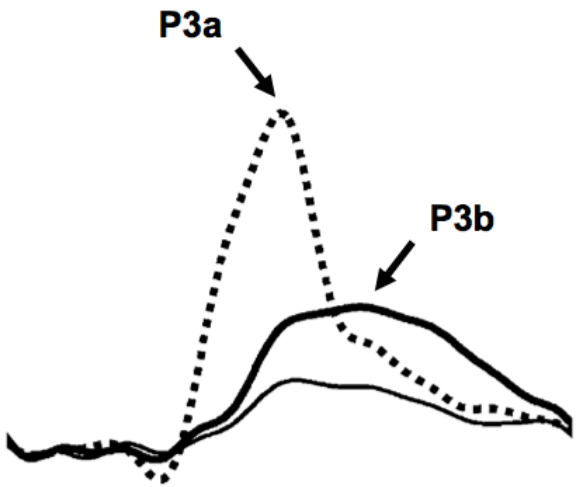

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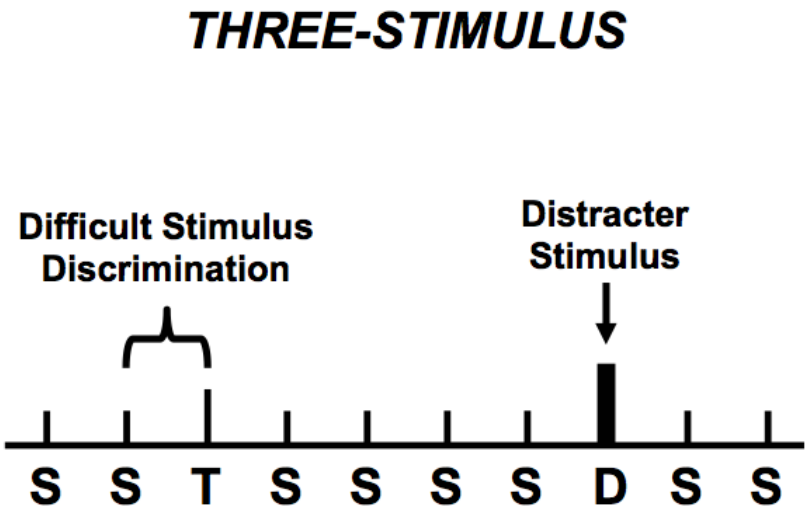

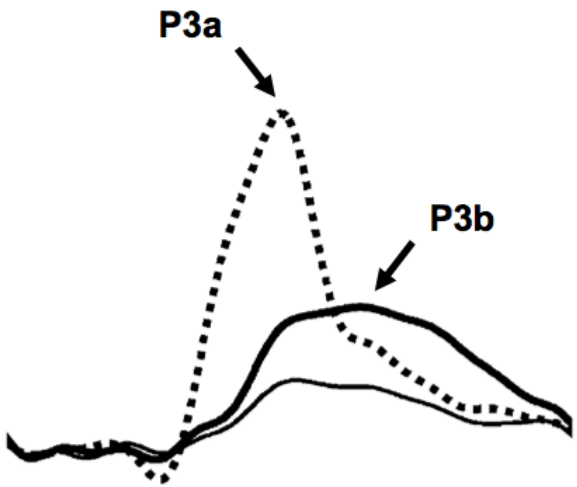

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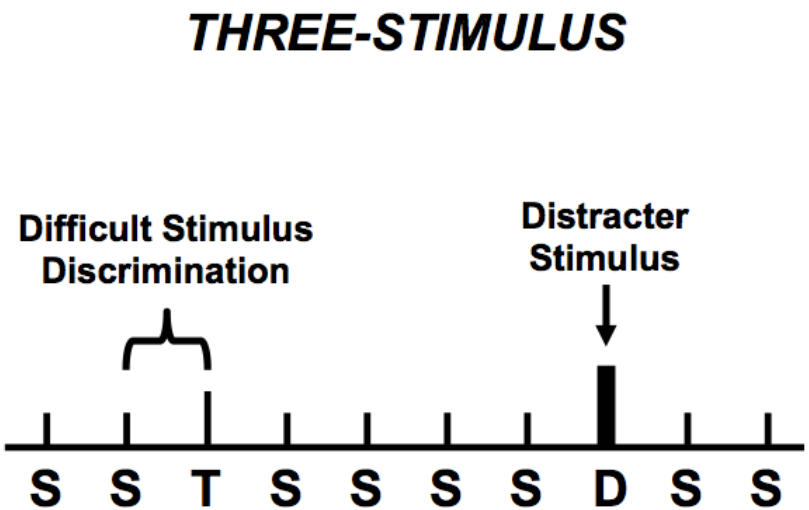

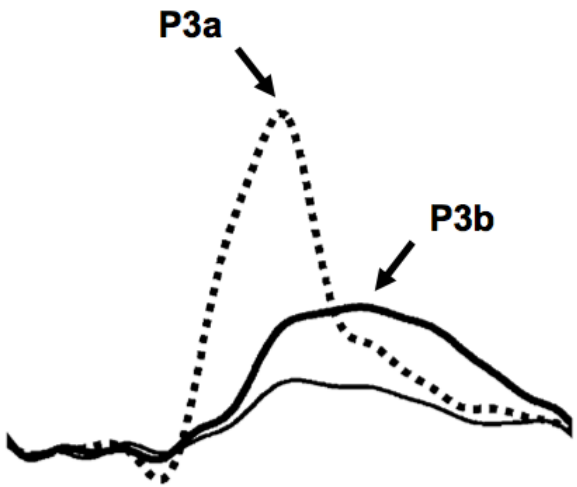

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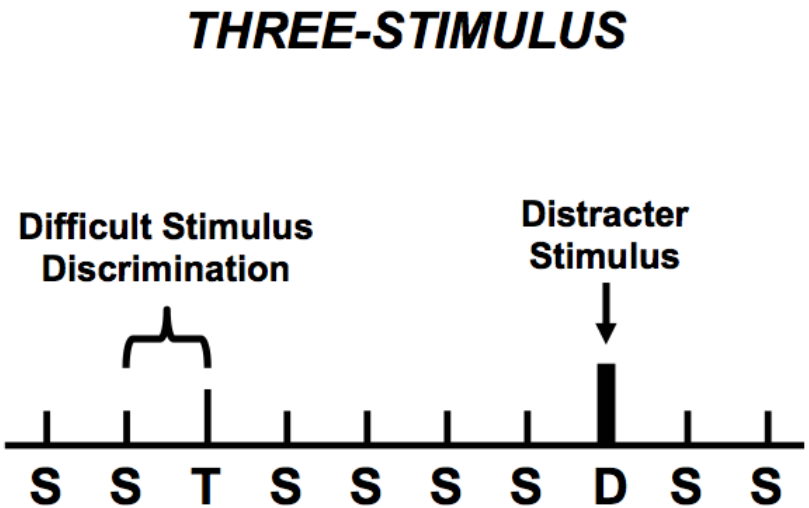

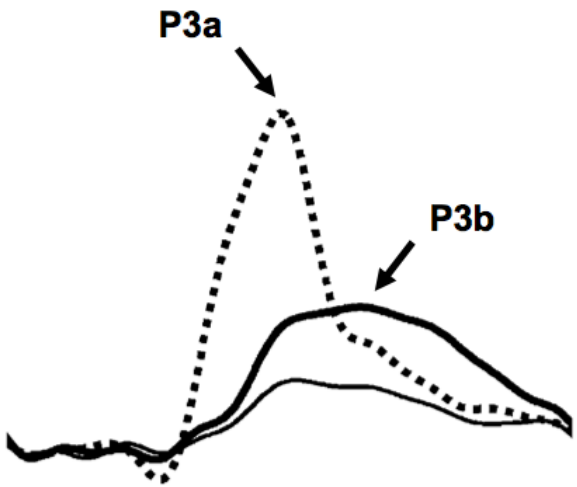

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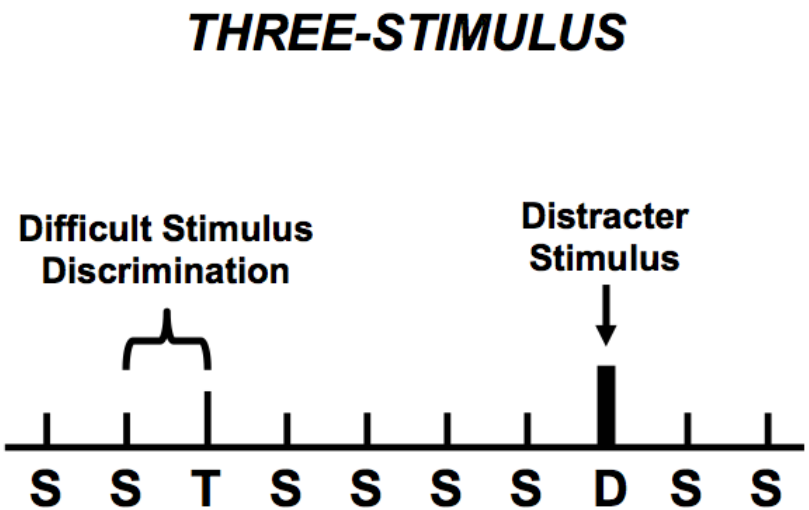

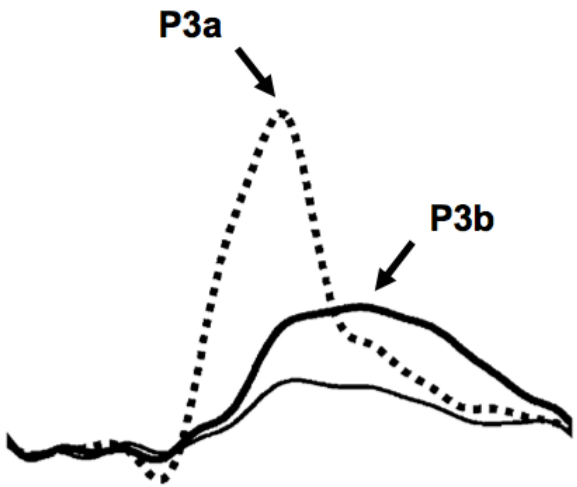

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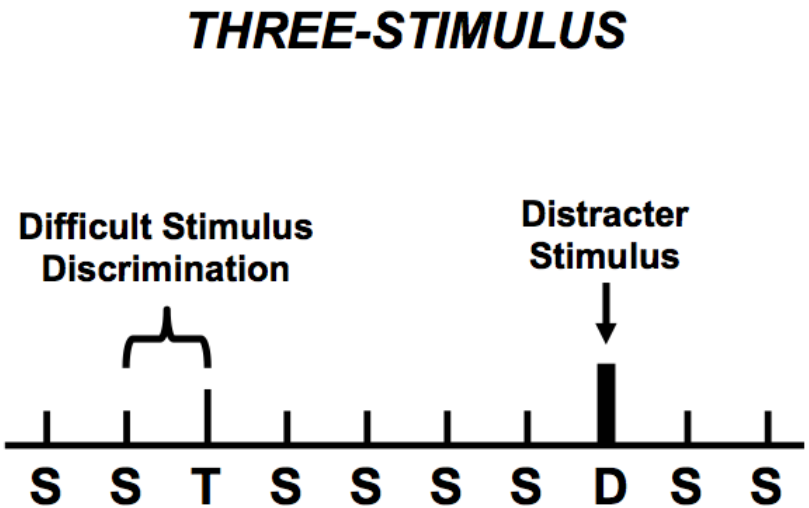

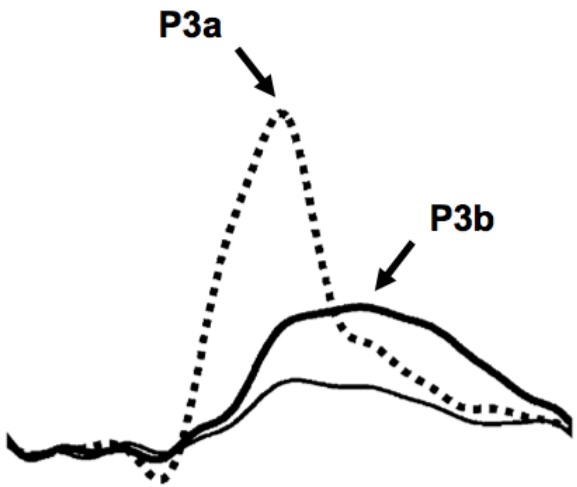

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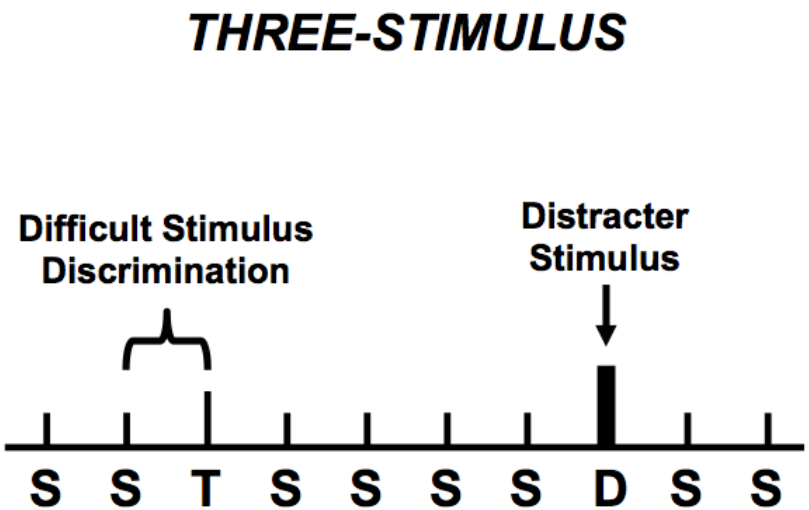

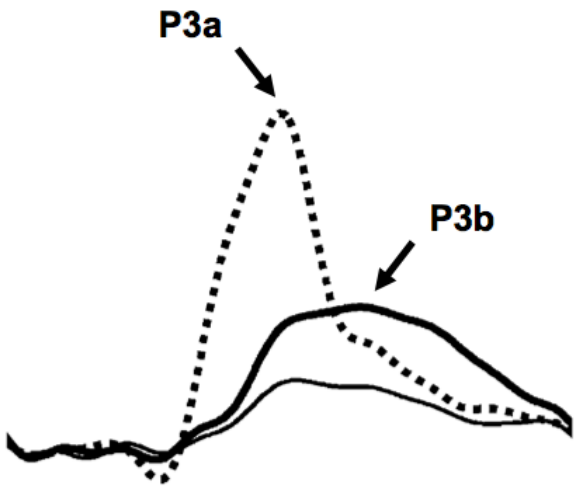

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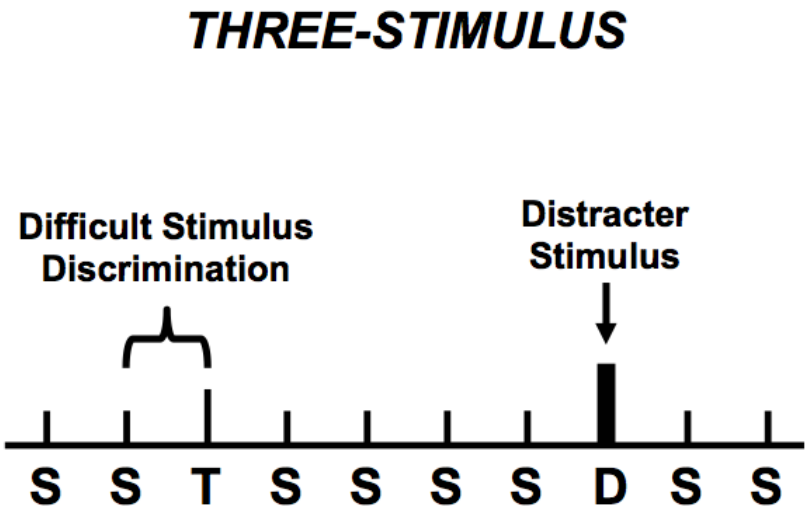

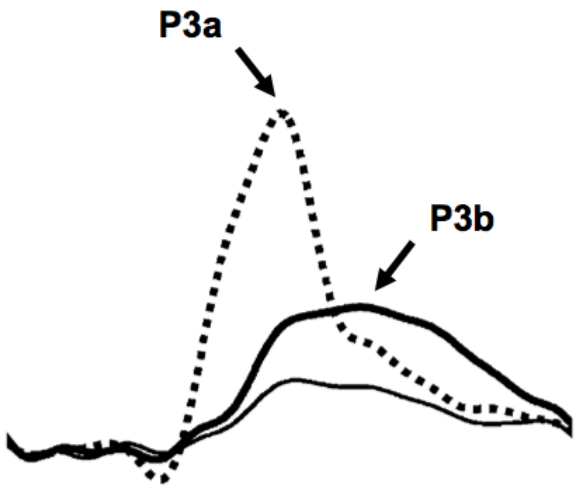

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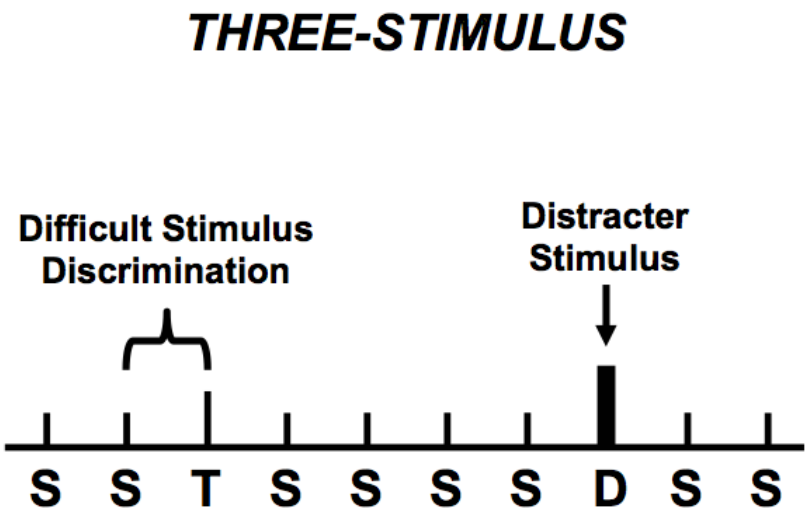

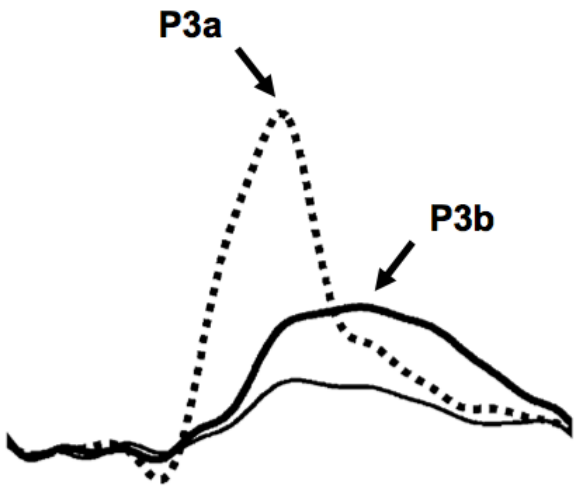

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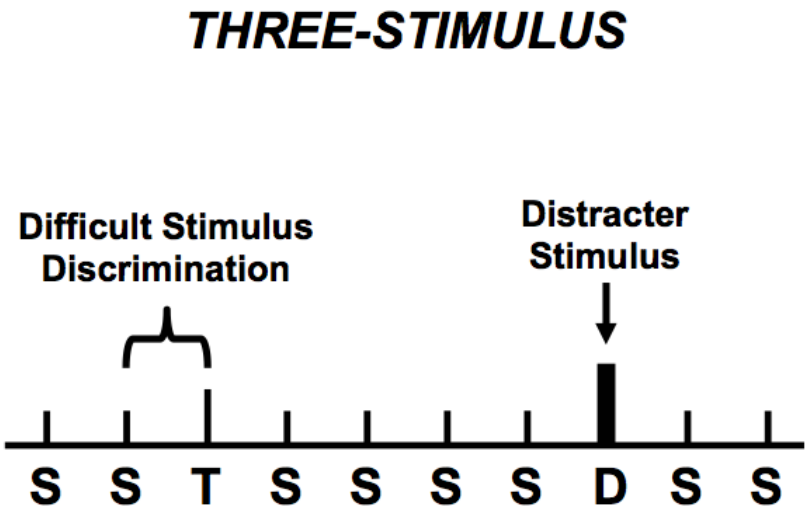

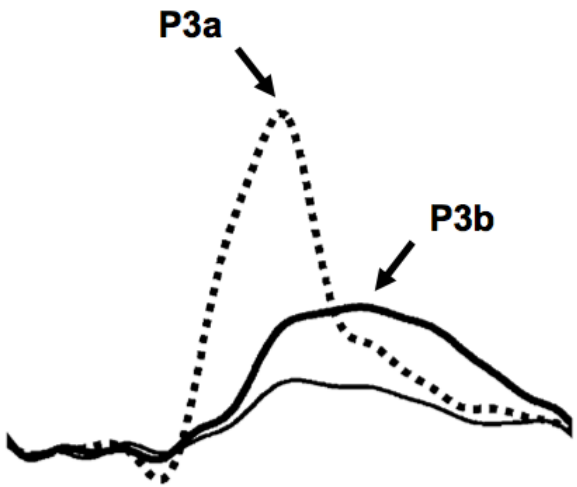

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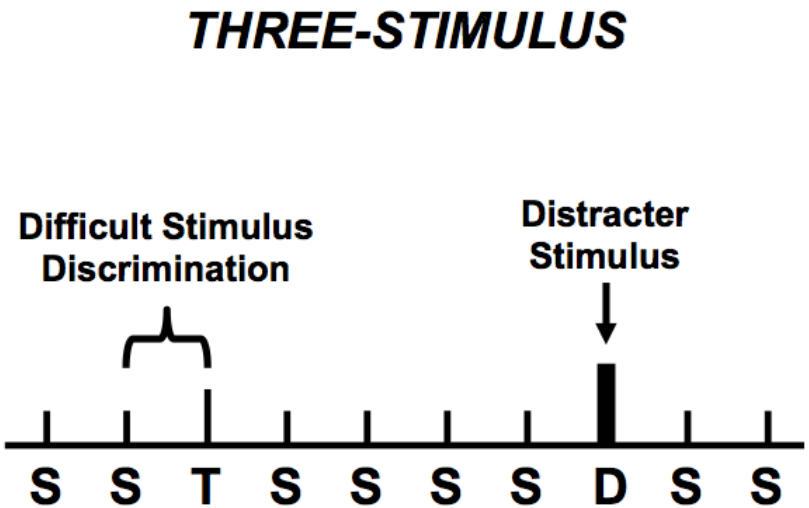

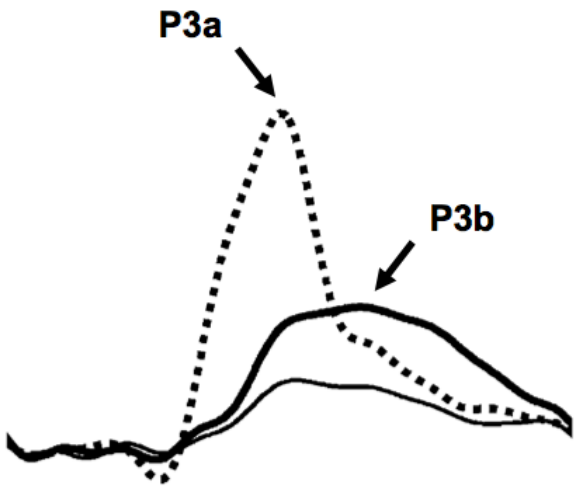

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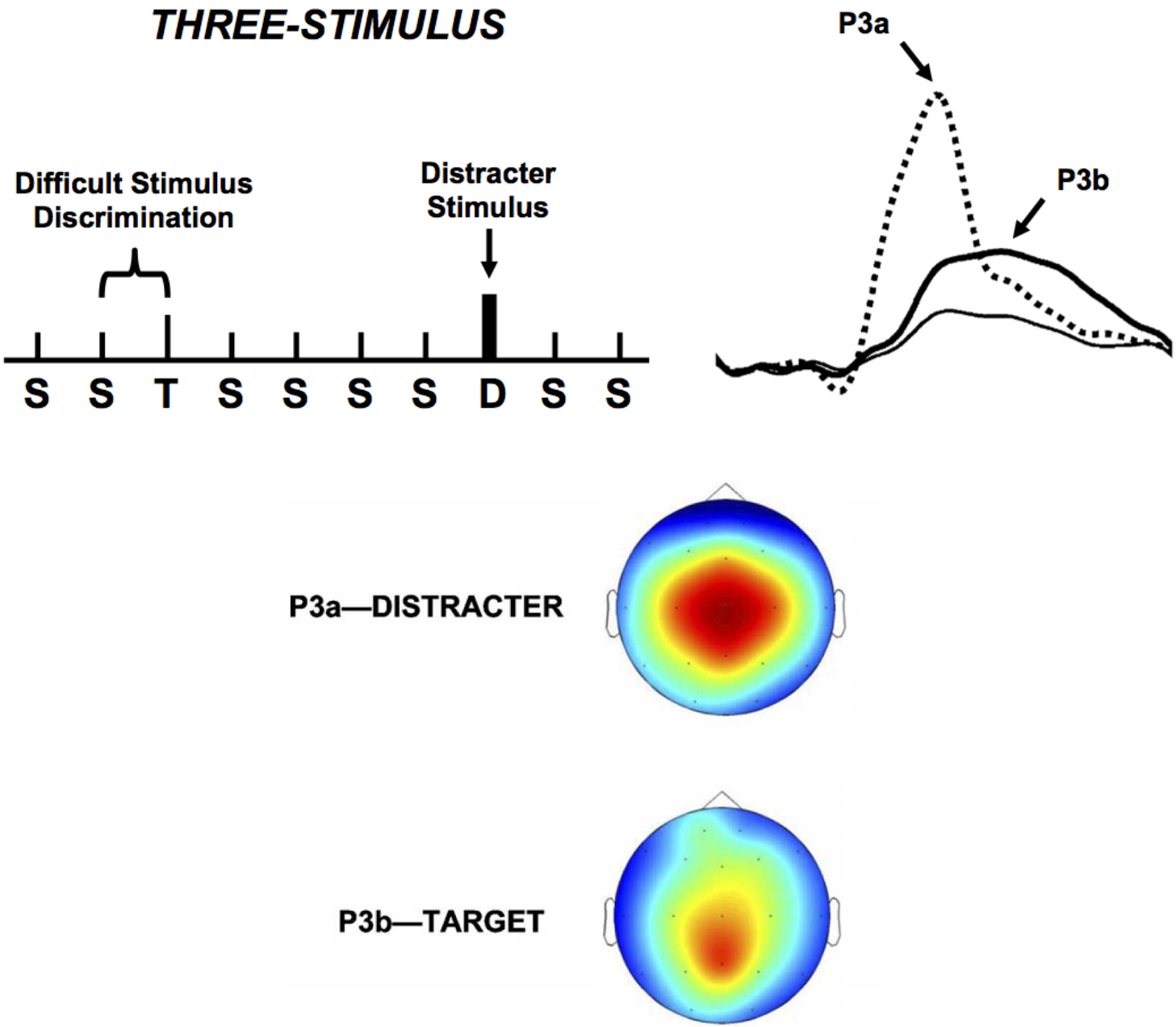
THREE-STIMULUS
Difficult Stimulus Discrimination
Distracter Stimulus
S S T S S S S D S S
P3a
P3b
P3a—DISTRACTER
P3b—TARGET

My P300's Bigger Than Yours

Amplitude and latency of ERP components vary between individuals, and there is evidence for effects of:

- age;

My P300's Bigger Than Yours

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- time of day, fatigue/arousal

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- ...

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- Visual perimetry, audiometry, etc. with infants, animals.

Average large numbers of ERPs

Classify single ERPs

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- Communication (e.g. the Farwell-Donchin speller).

- Detection of mistakes (via "error-related negativity" or ERN) in BCI and other tasks.

Average large numbers of ERPs

Classify single ERPs

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- Monitoring the depth of anaesthesia.
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- Communication (e.g. the Farwell-Donchin speller).
- "Triage" of potential targets in human stimulus-processing tasks.
- Detection of mistakes (via "error-related negativity" or ERN) in BCI and other tasks.

Average large numbers of ERPs

Classify single ERPs

"Cortically Coupled Computer Vision"

figures from Parra et al. 2008
(IEEE Signal Processing Magazine)

Credit: Digital Globe

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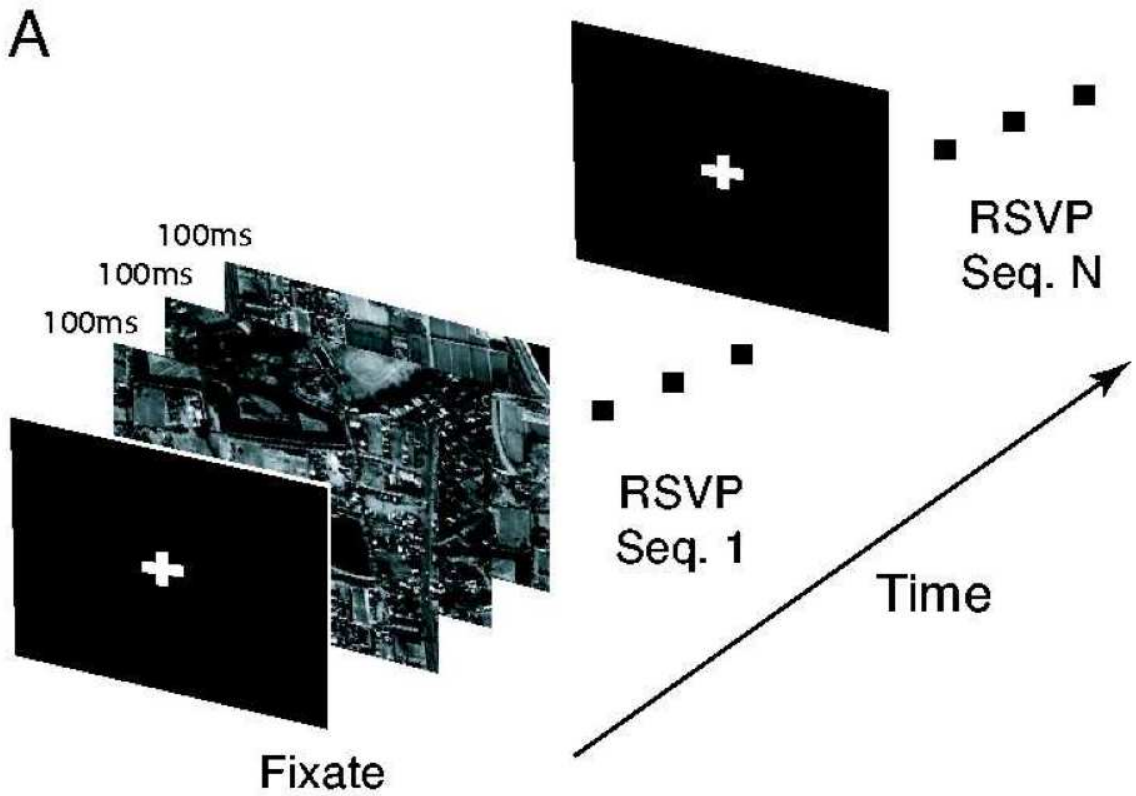

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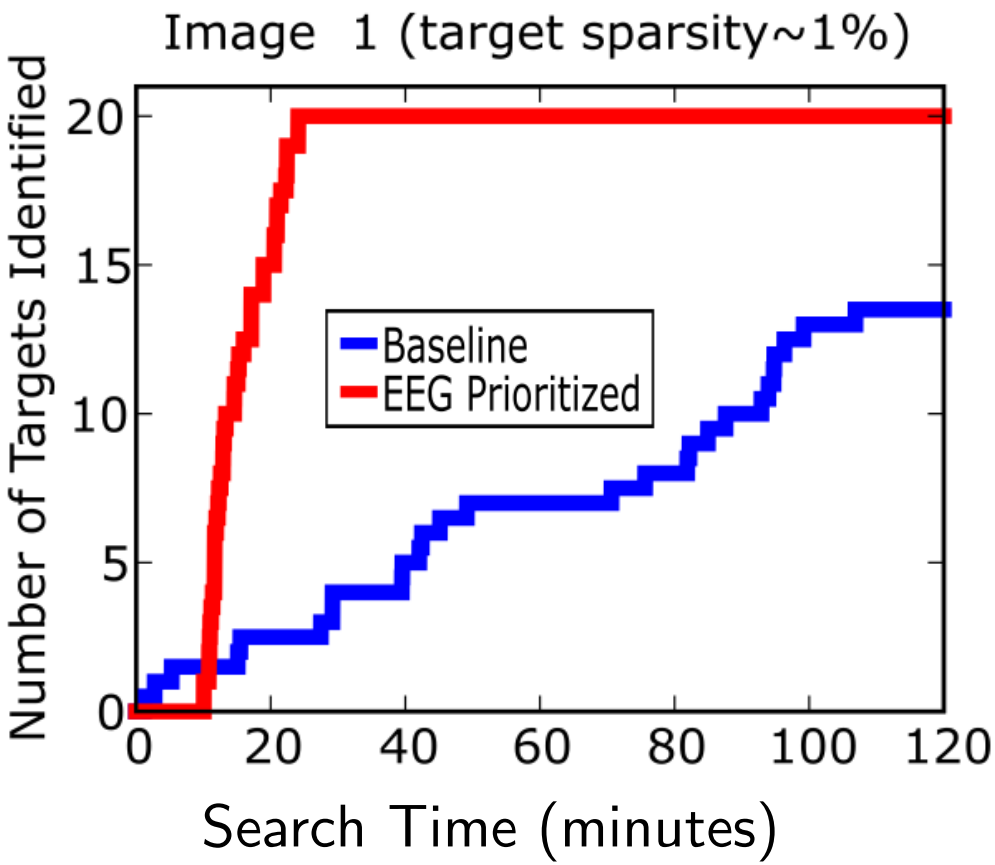

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Demo movie courtesy of Femke Nijboer (University of Tübingen & Fatronik, San Sebastián).

See also `http://www.youtube.com/watch?v=NlUPFpZswJk`

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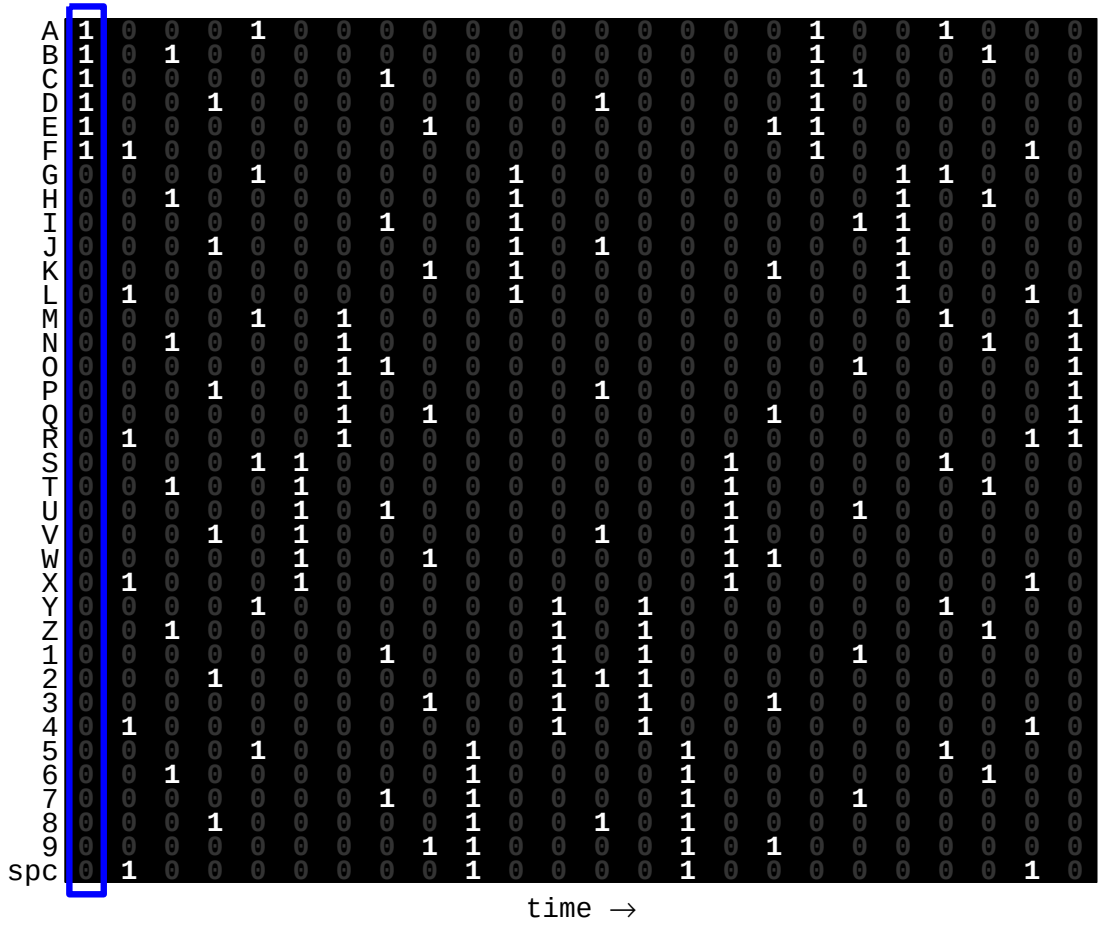

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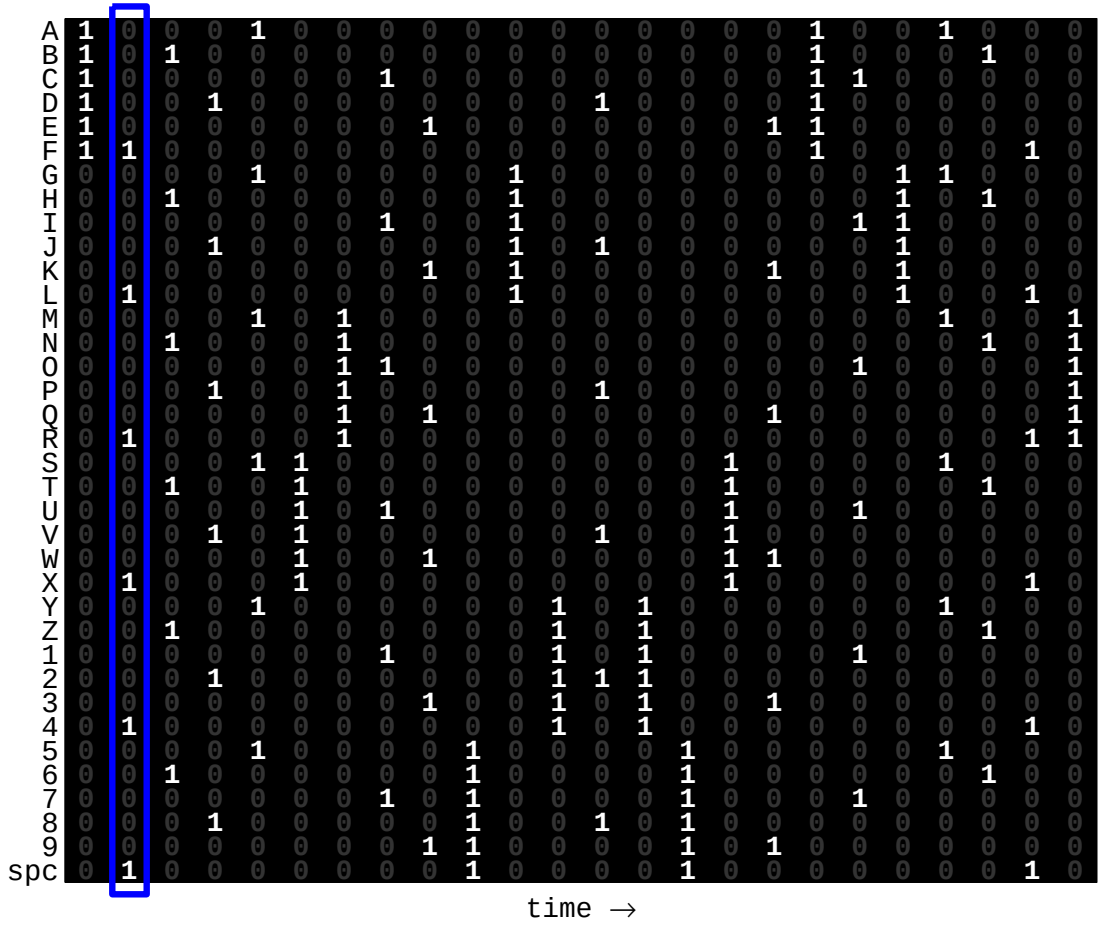

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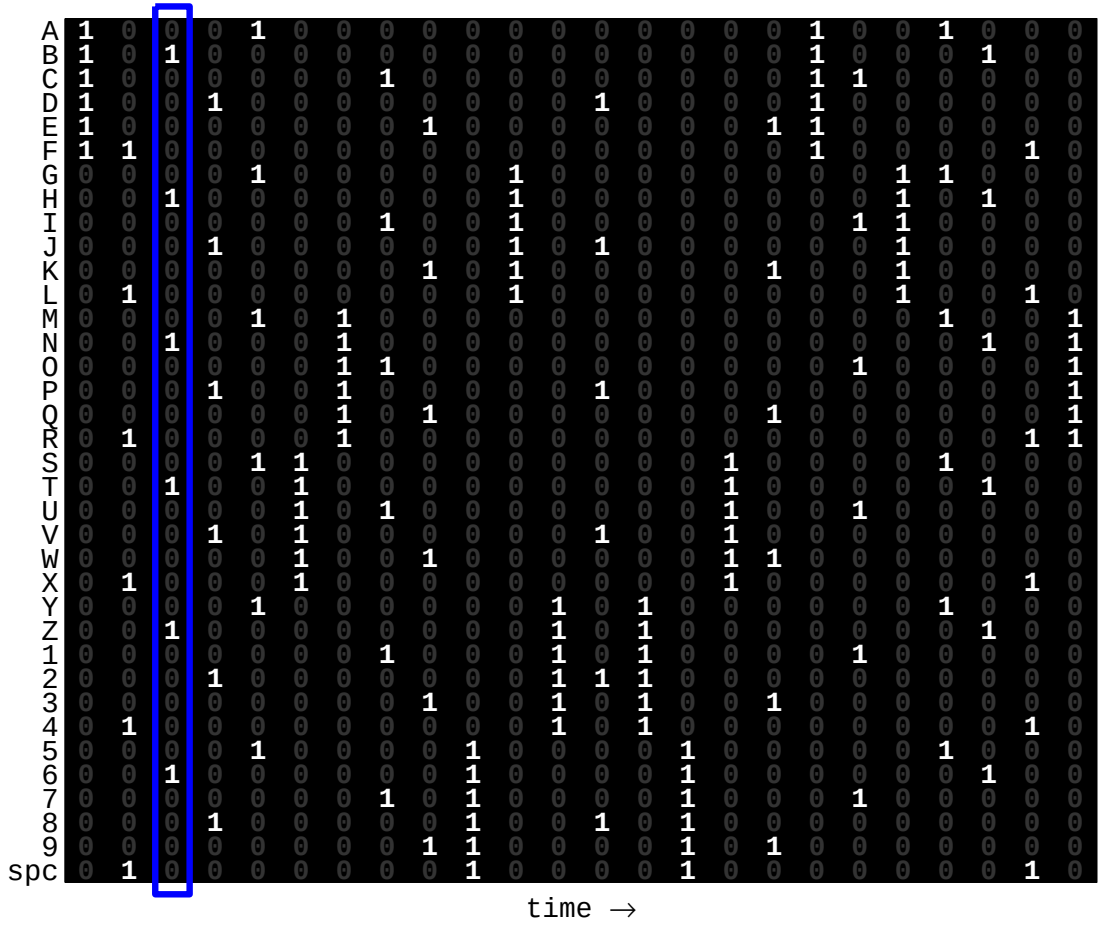

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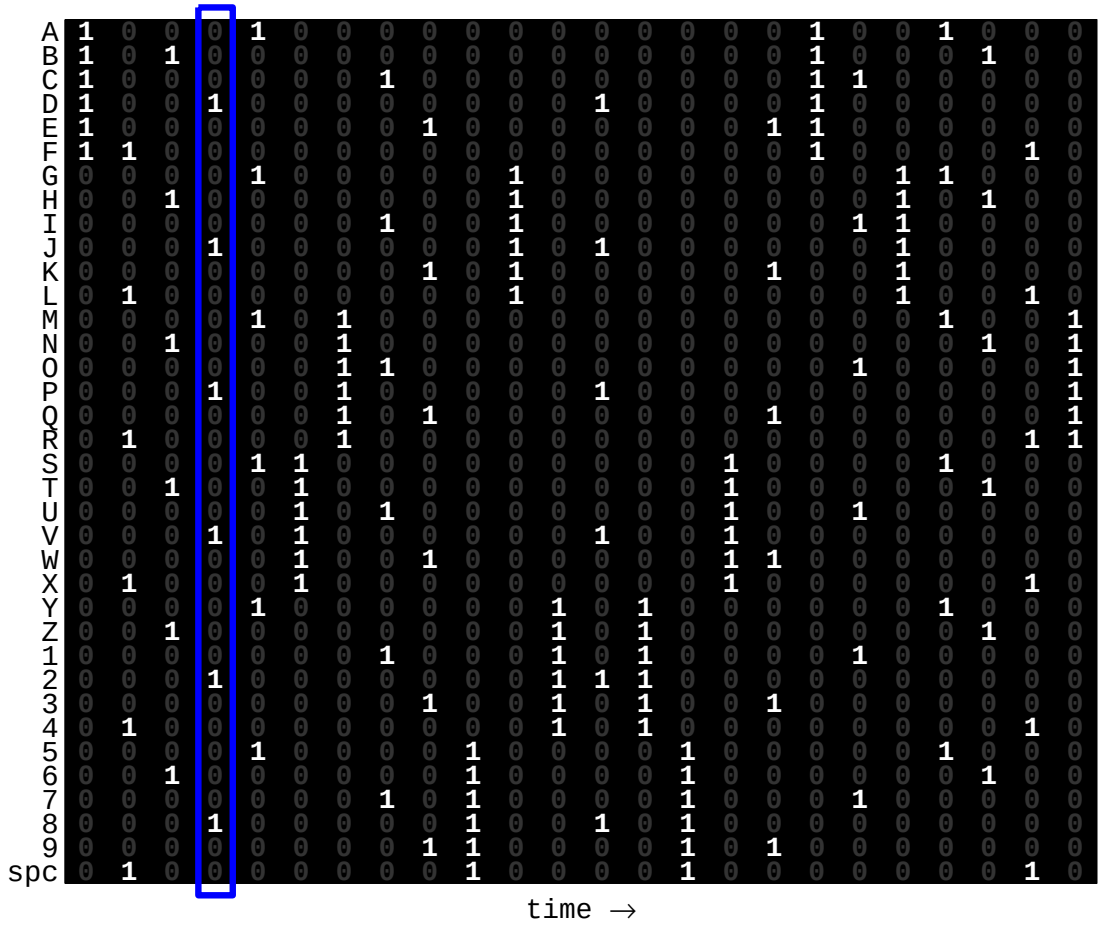

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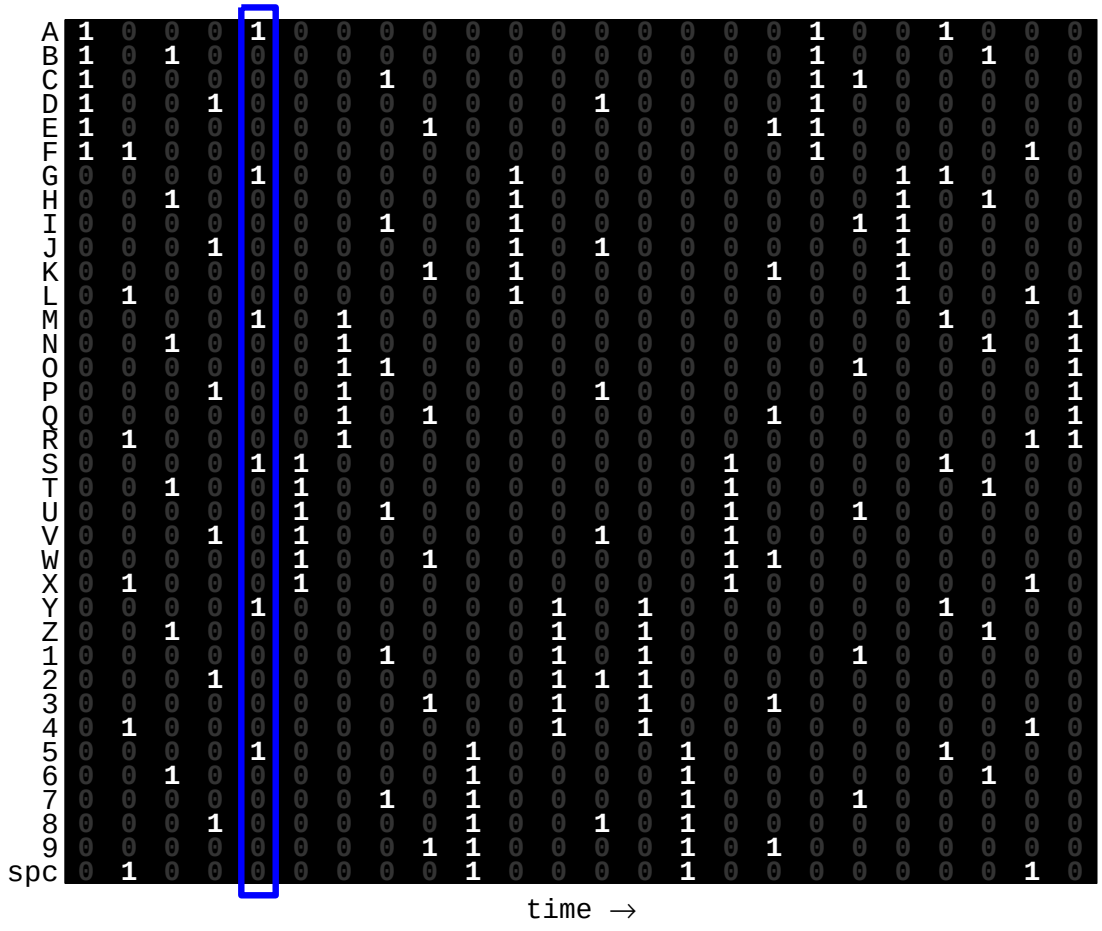

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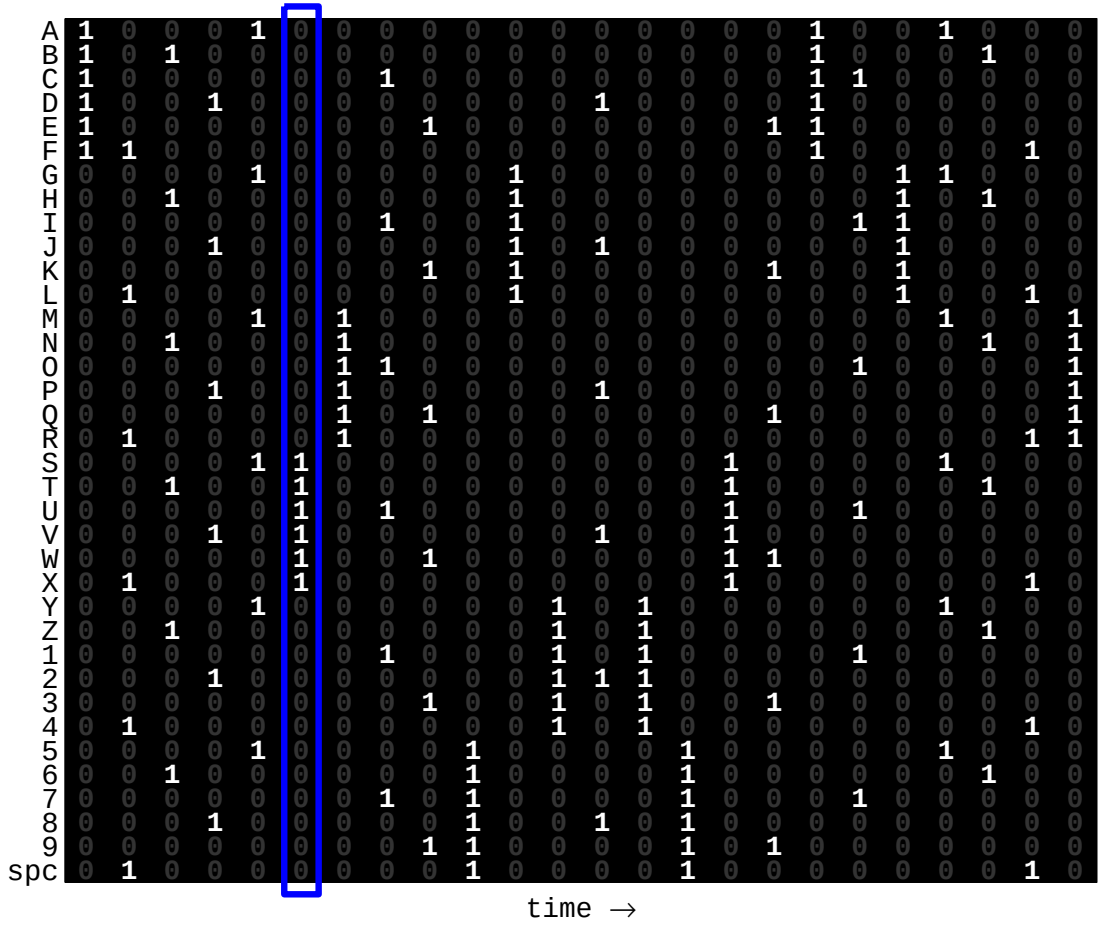

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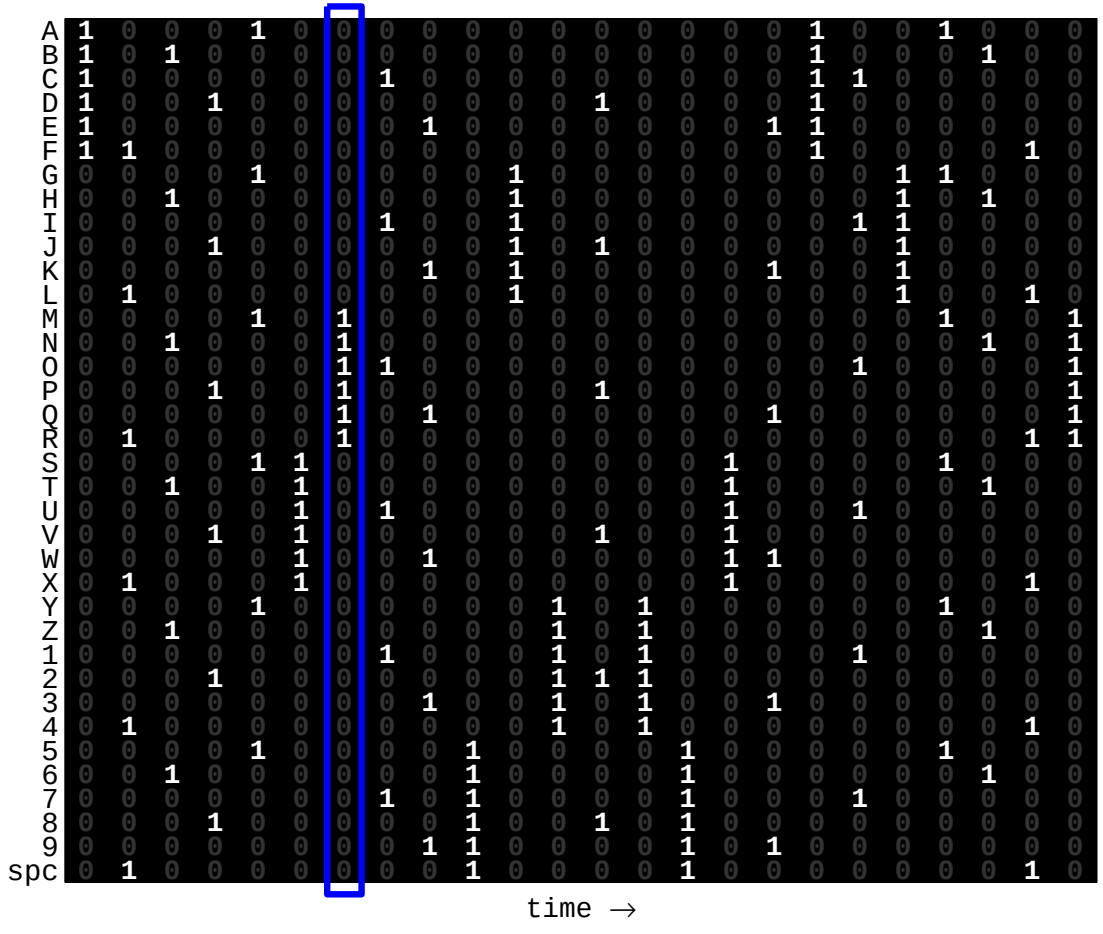

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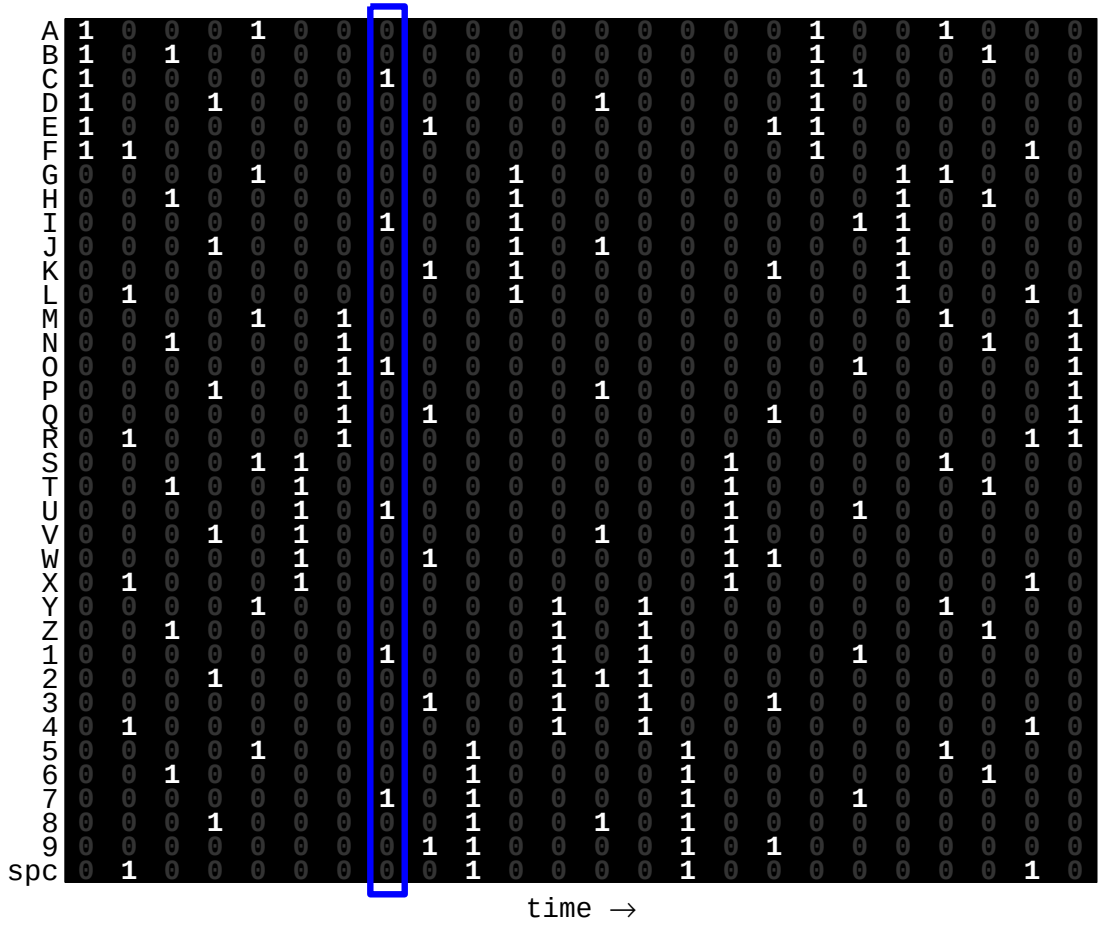

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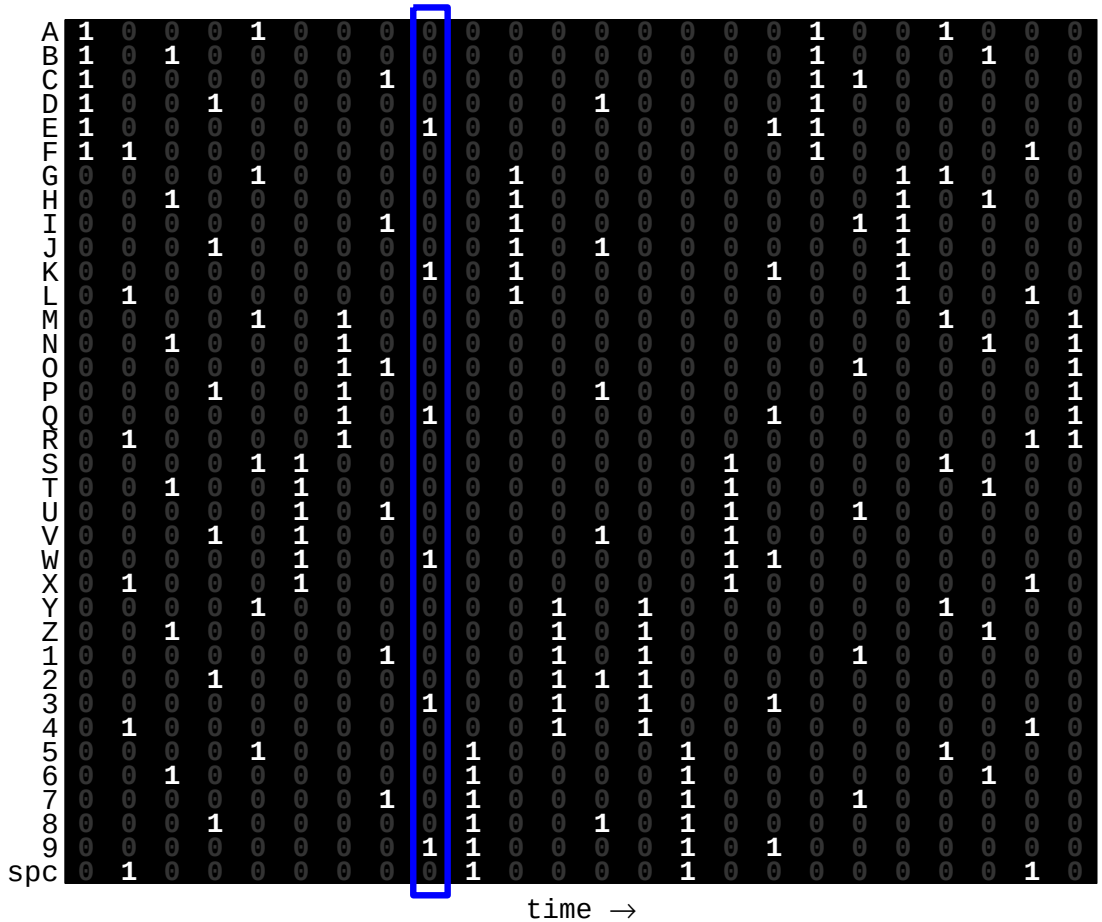

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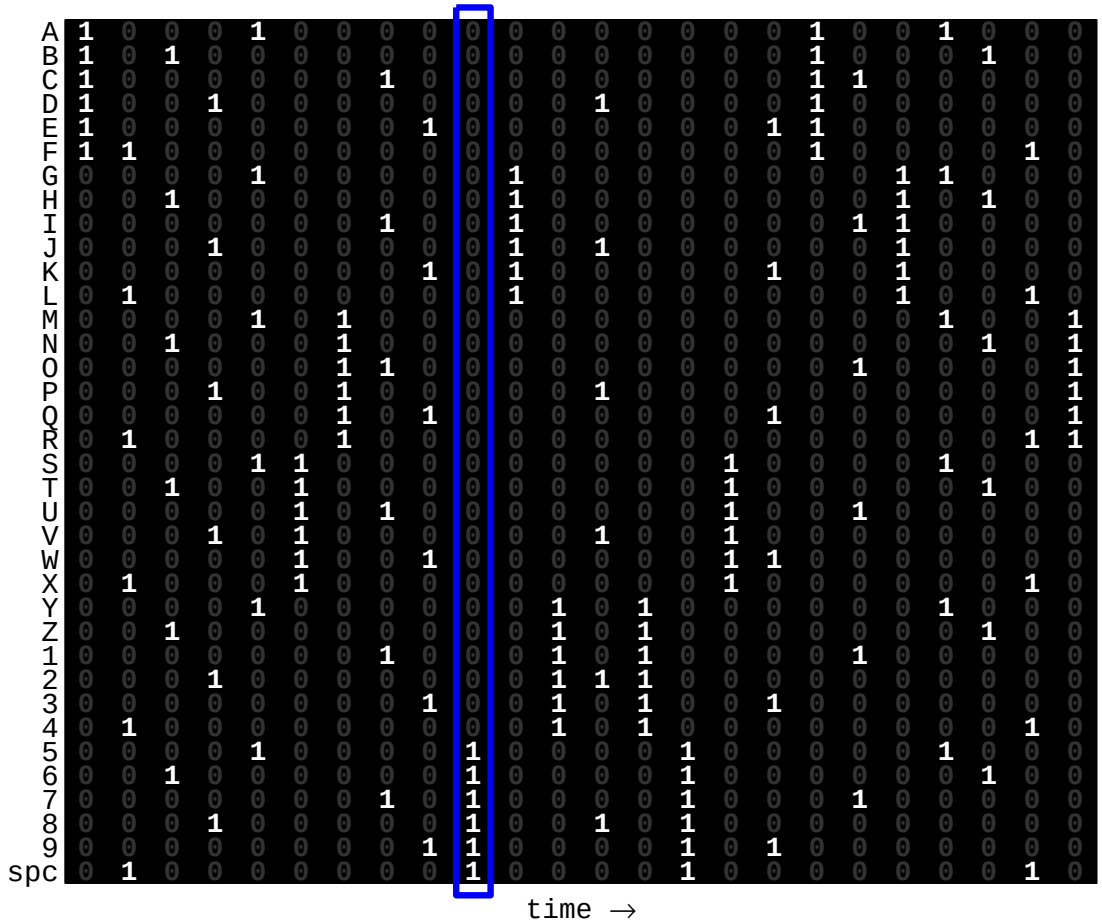

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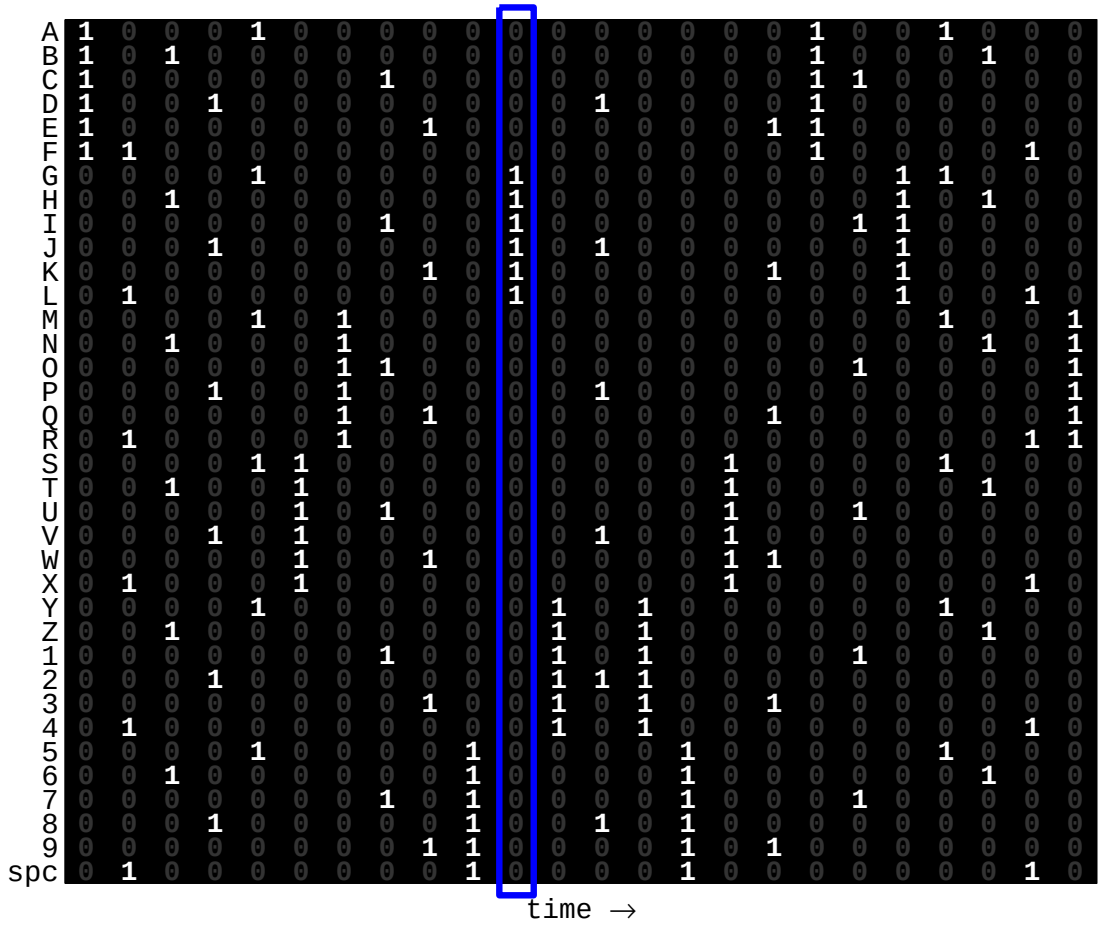

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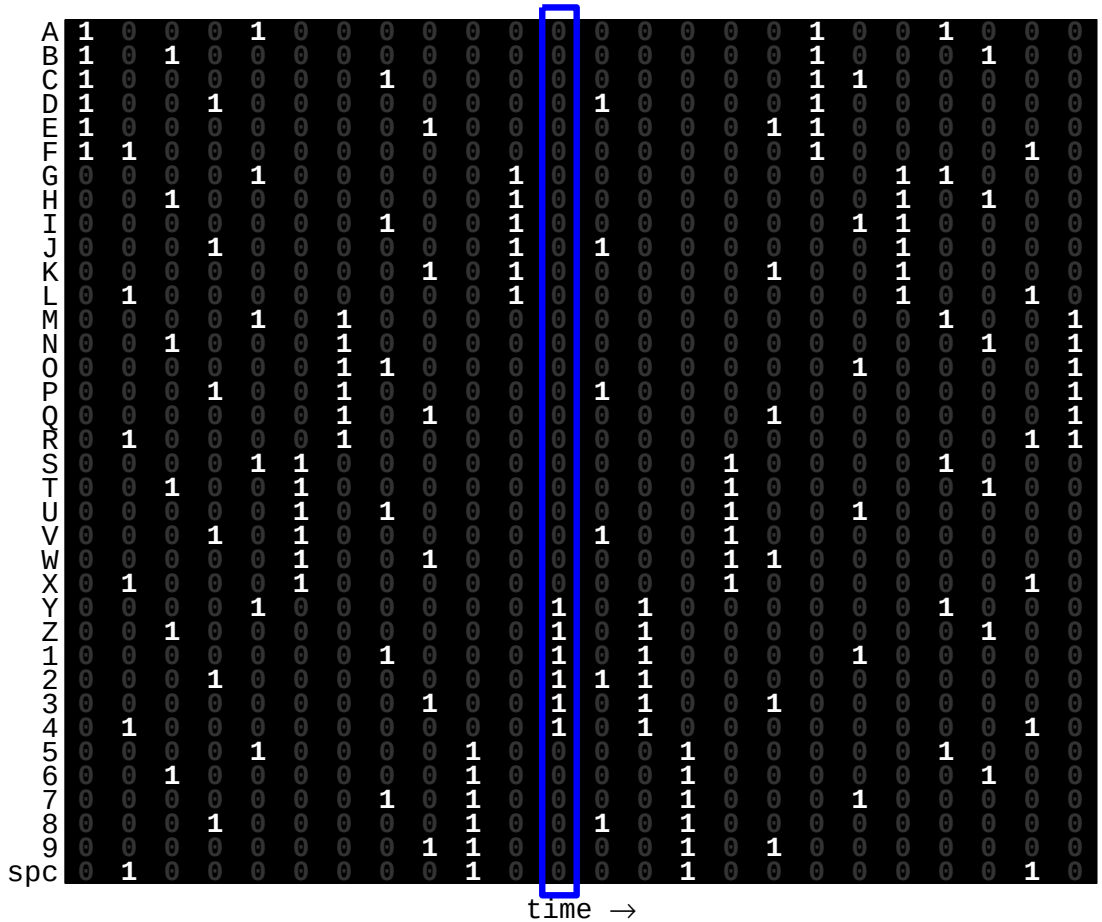

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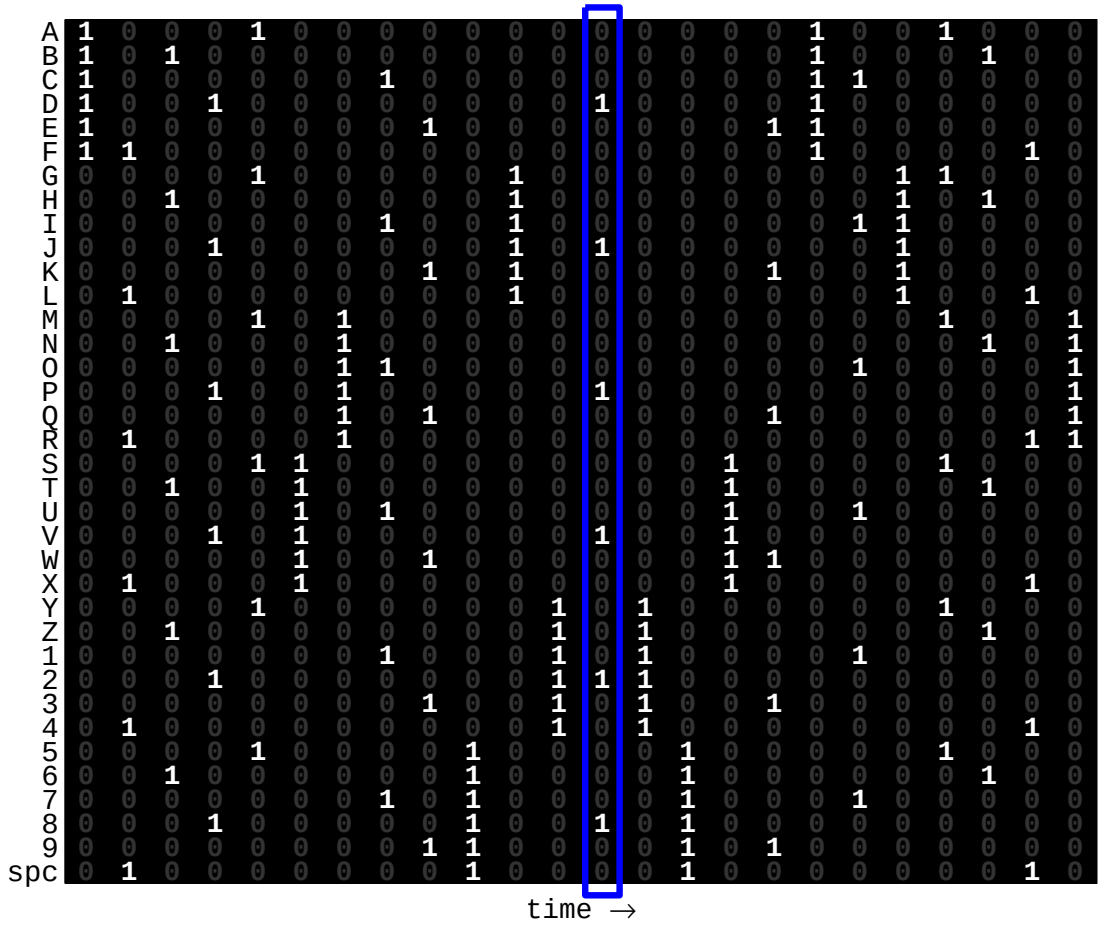

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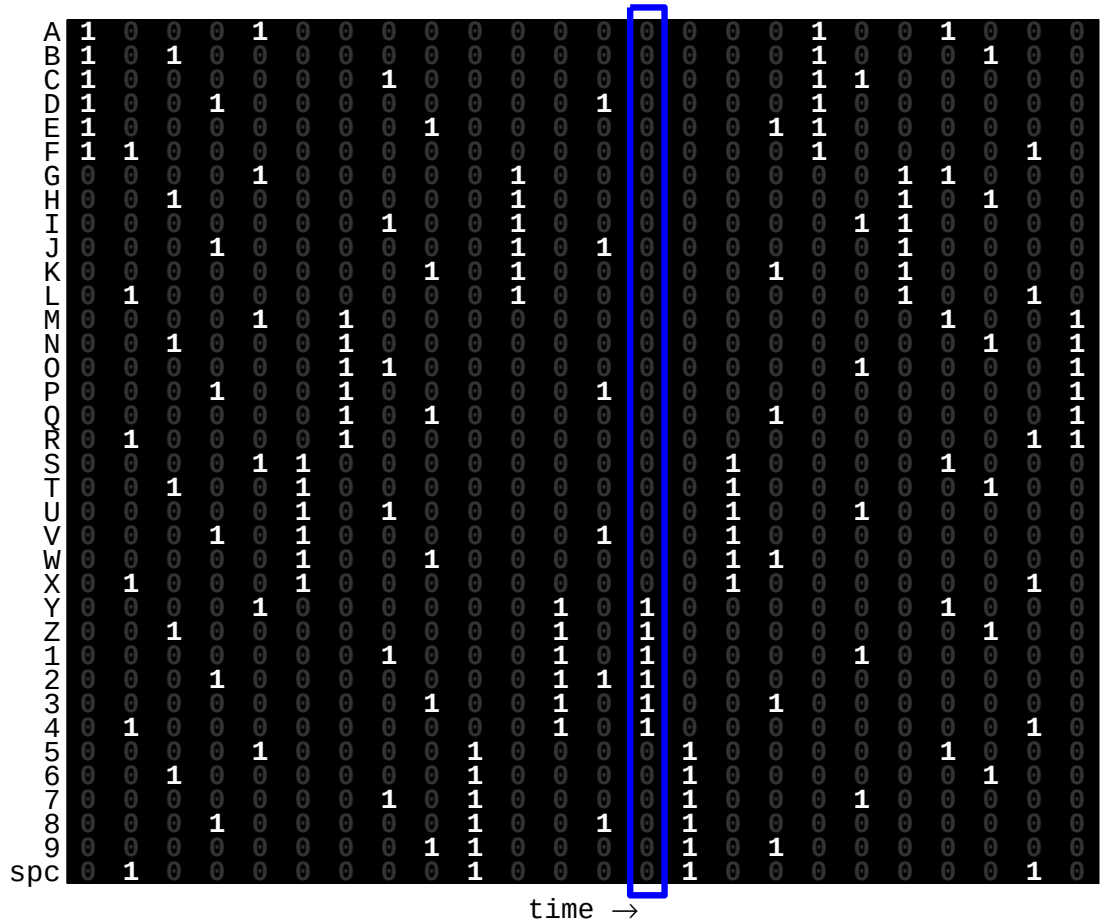

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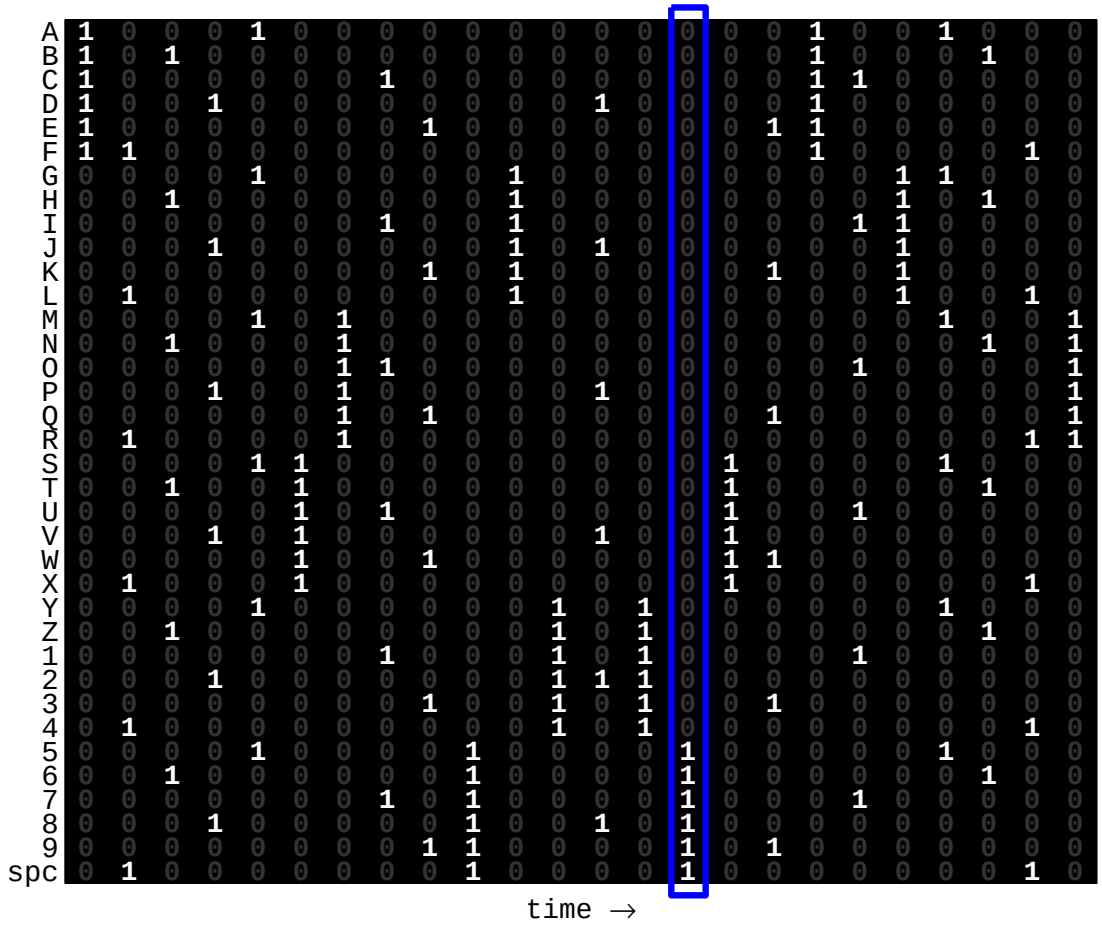

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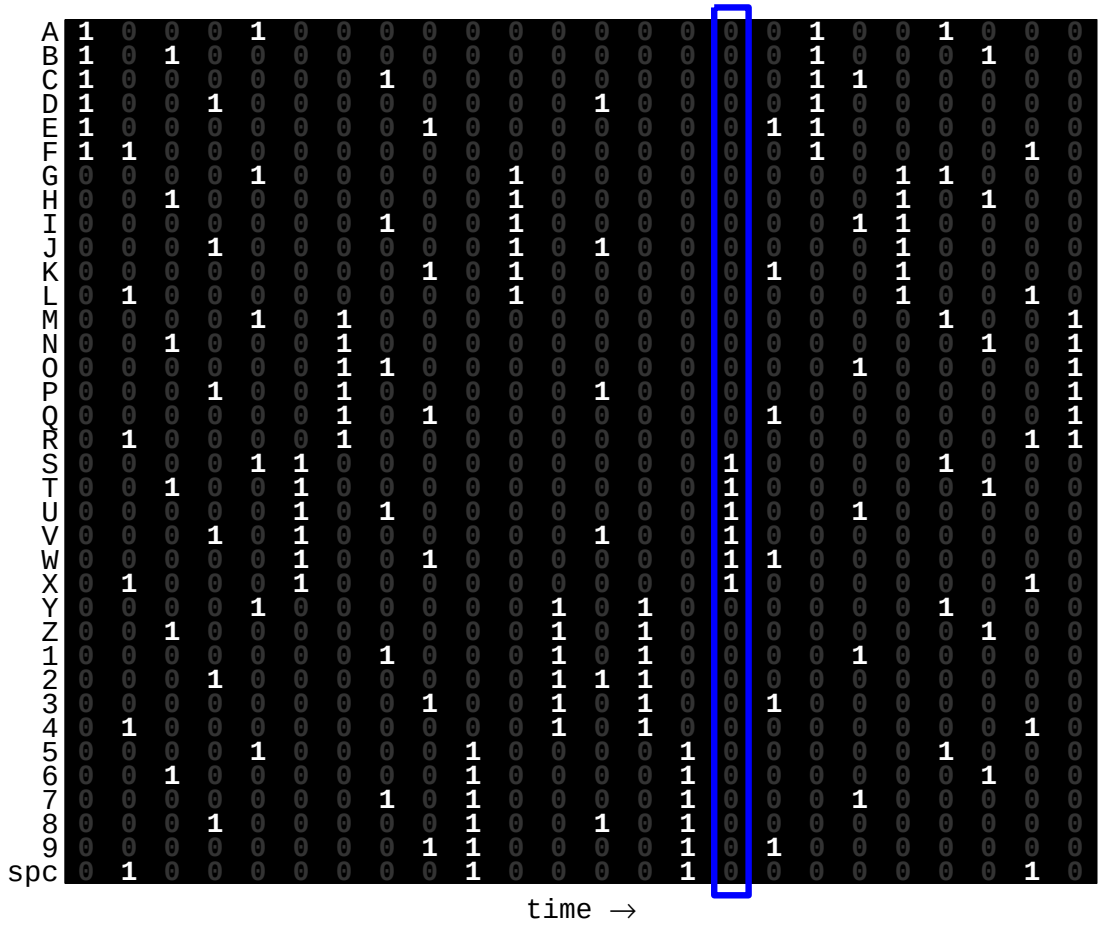

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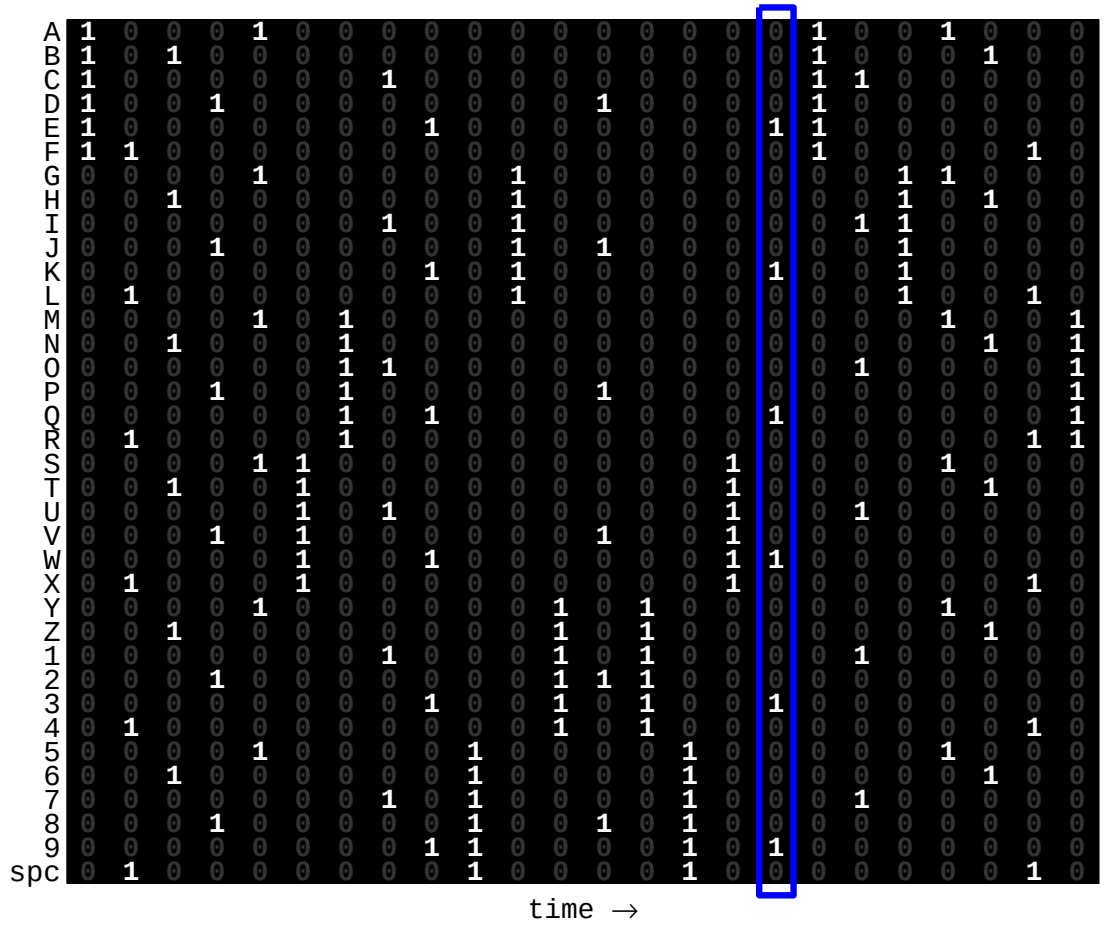

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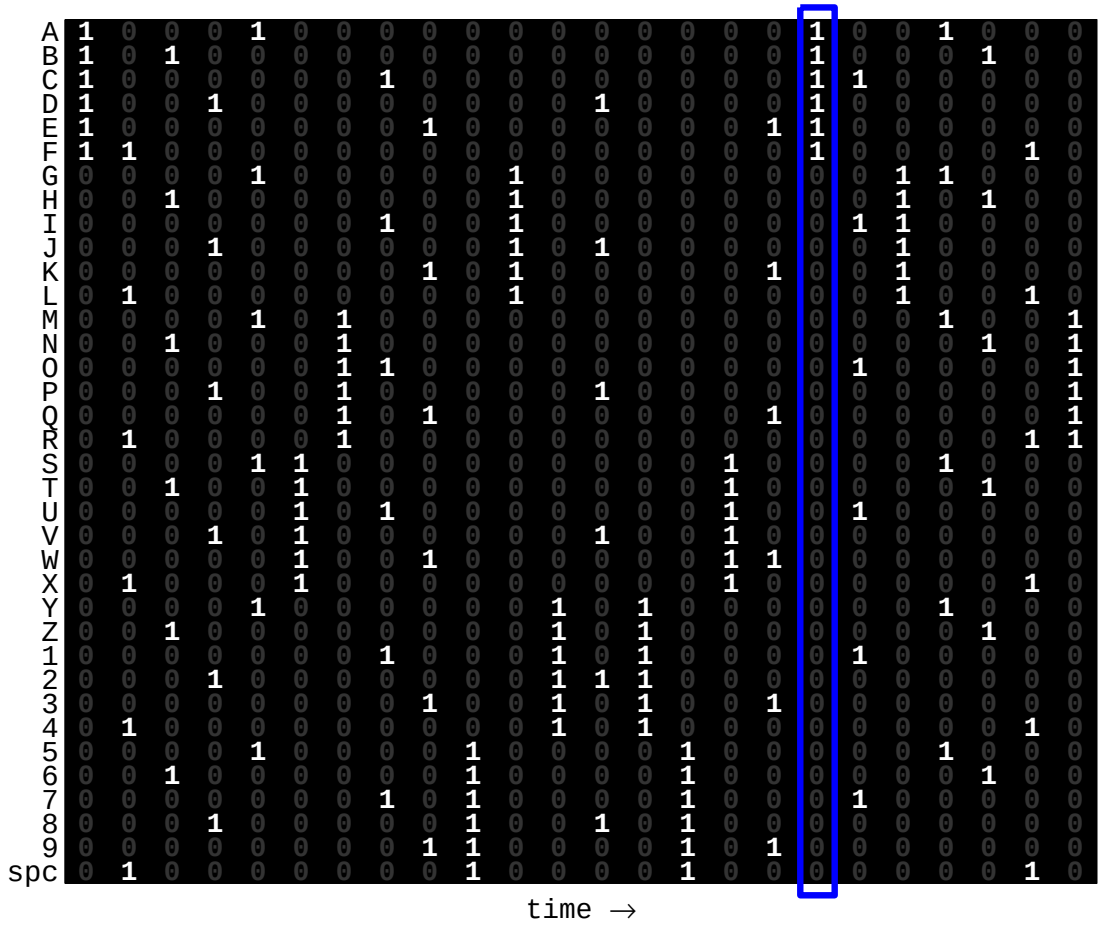

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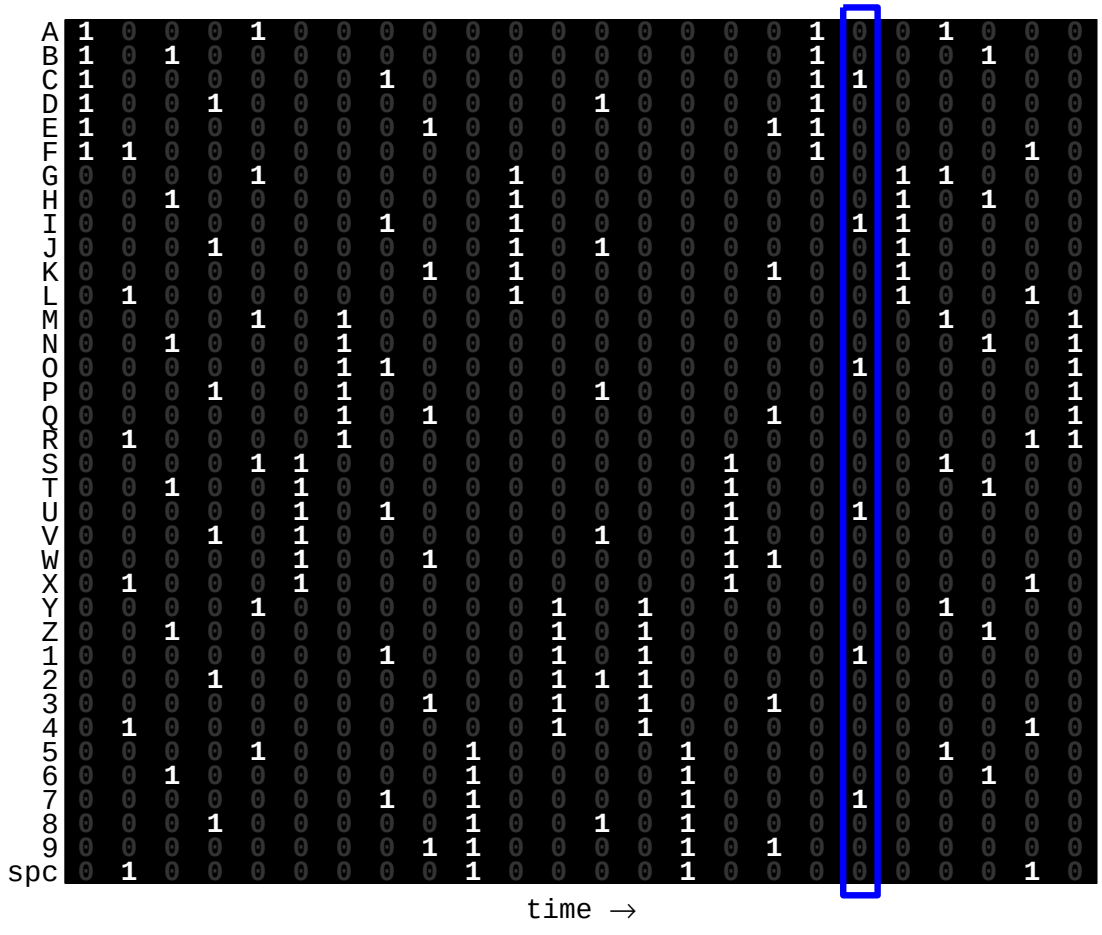

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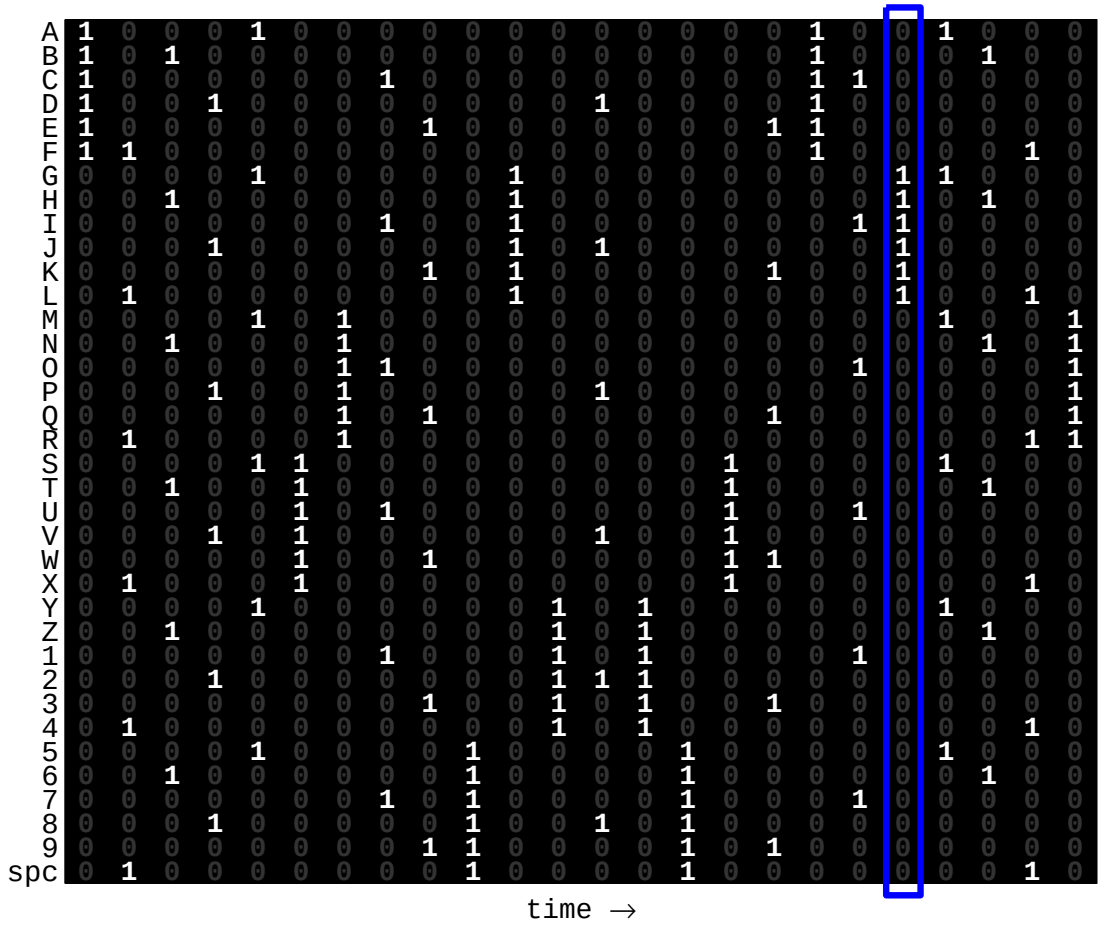

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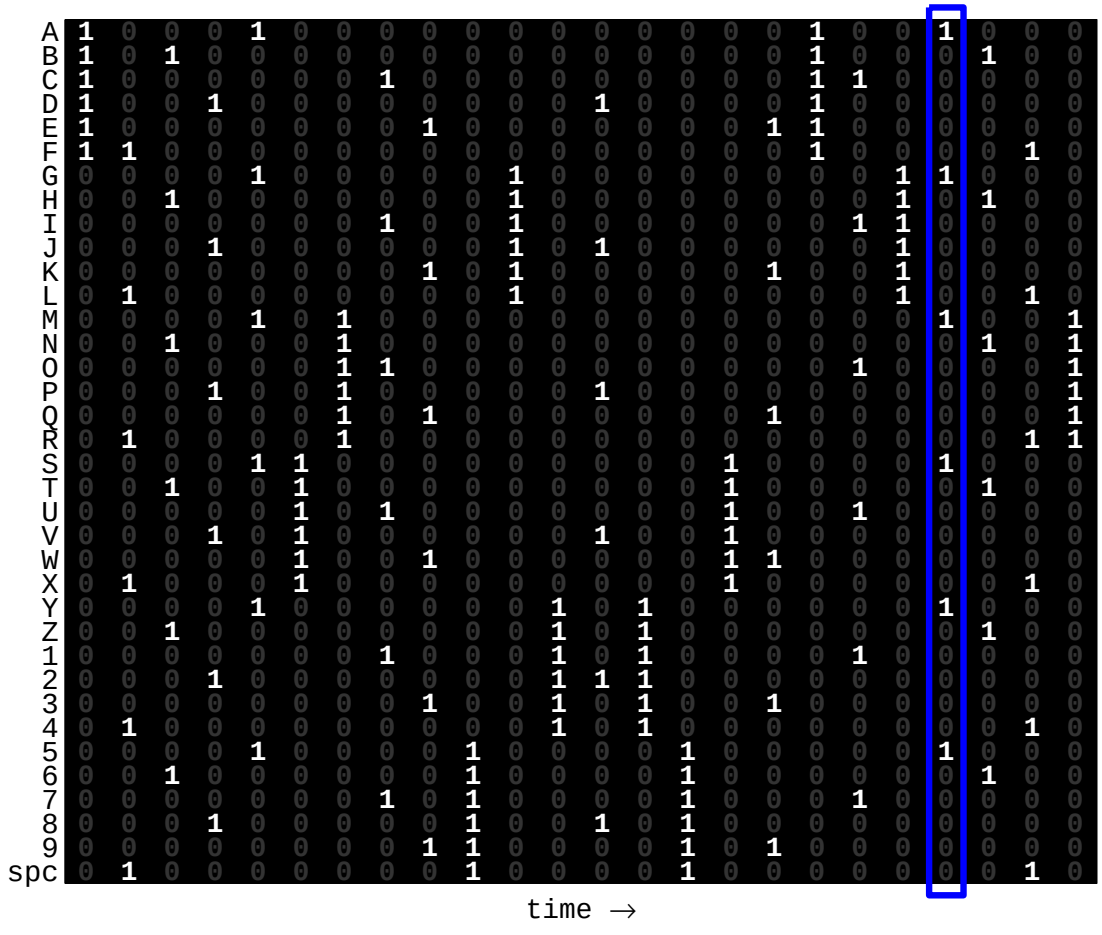

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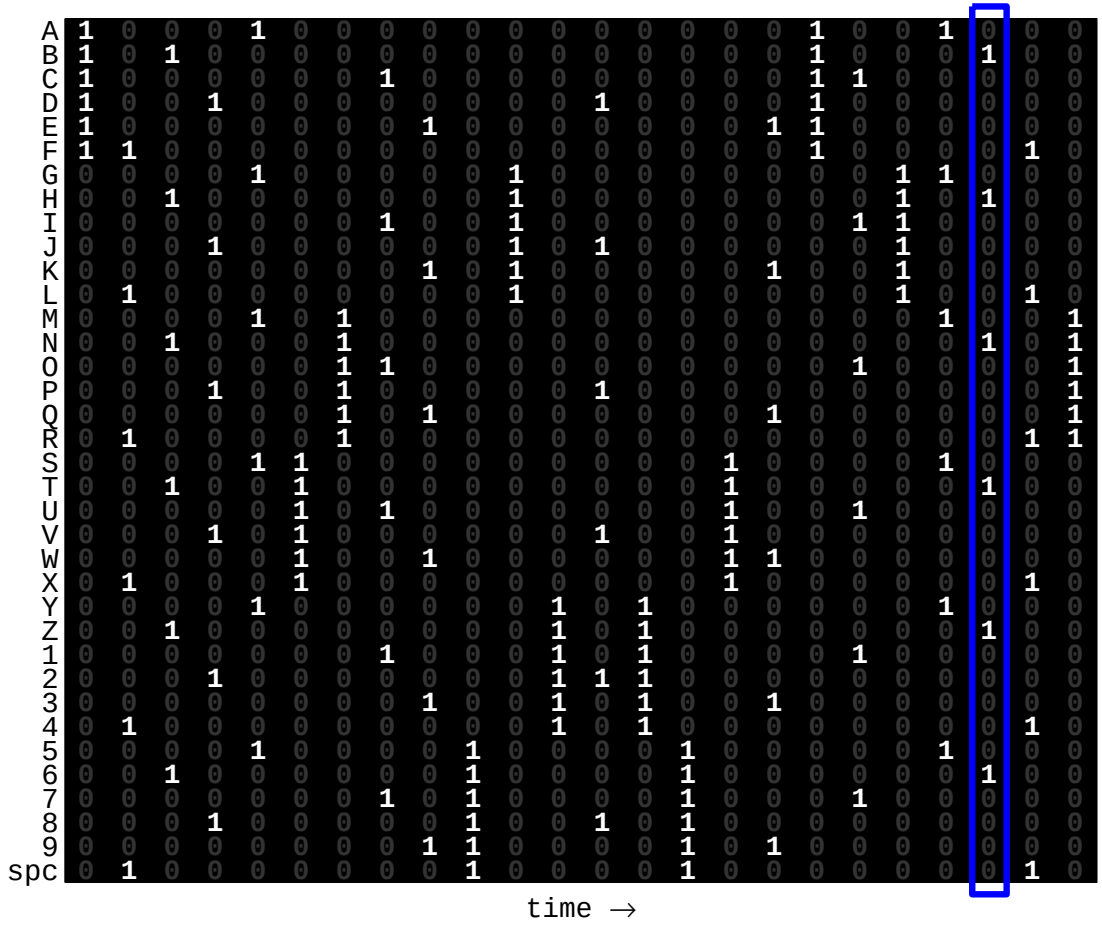

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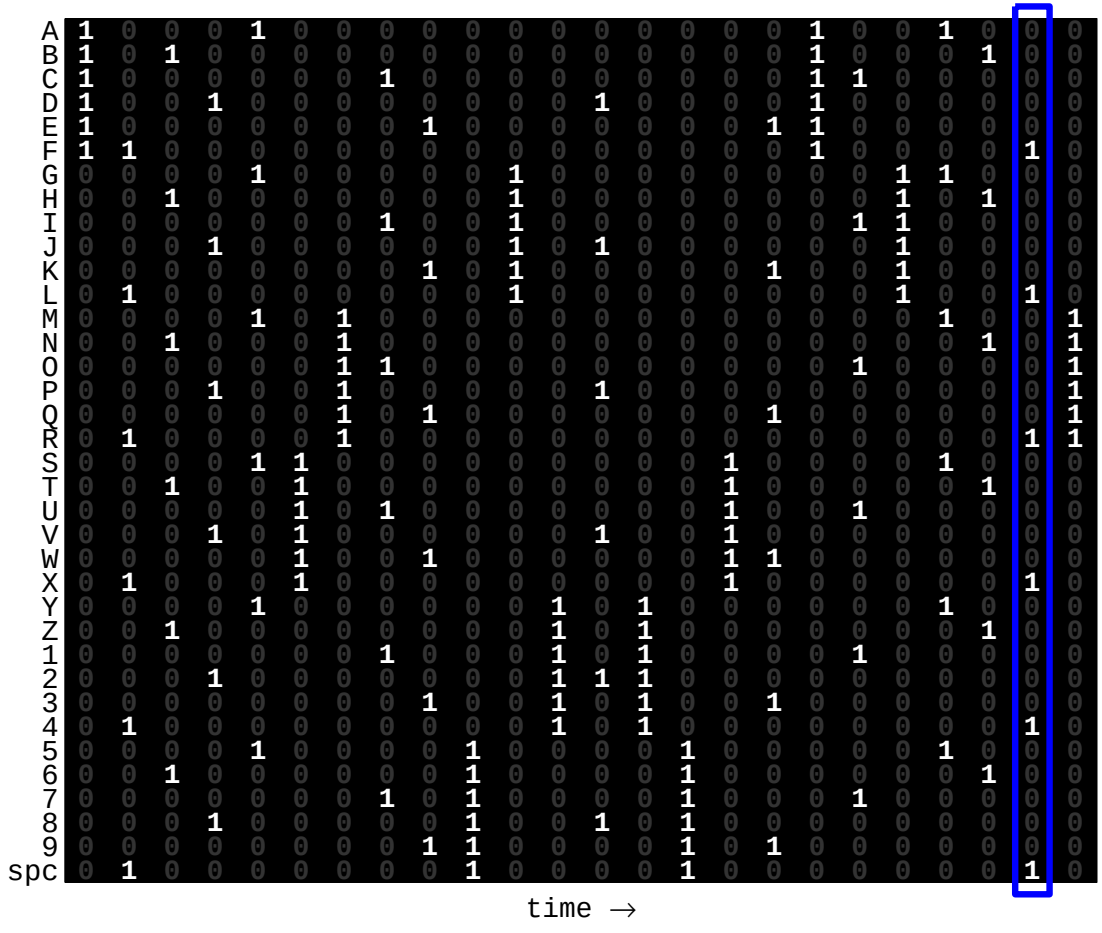

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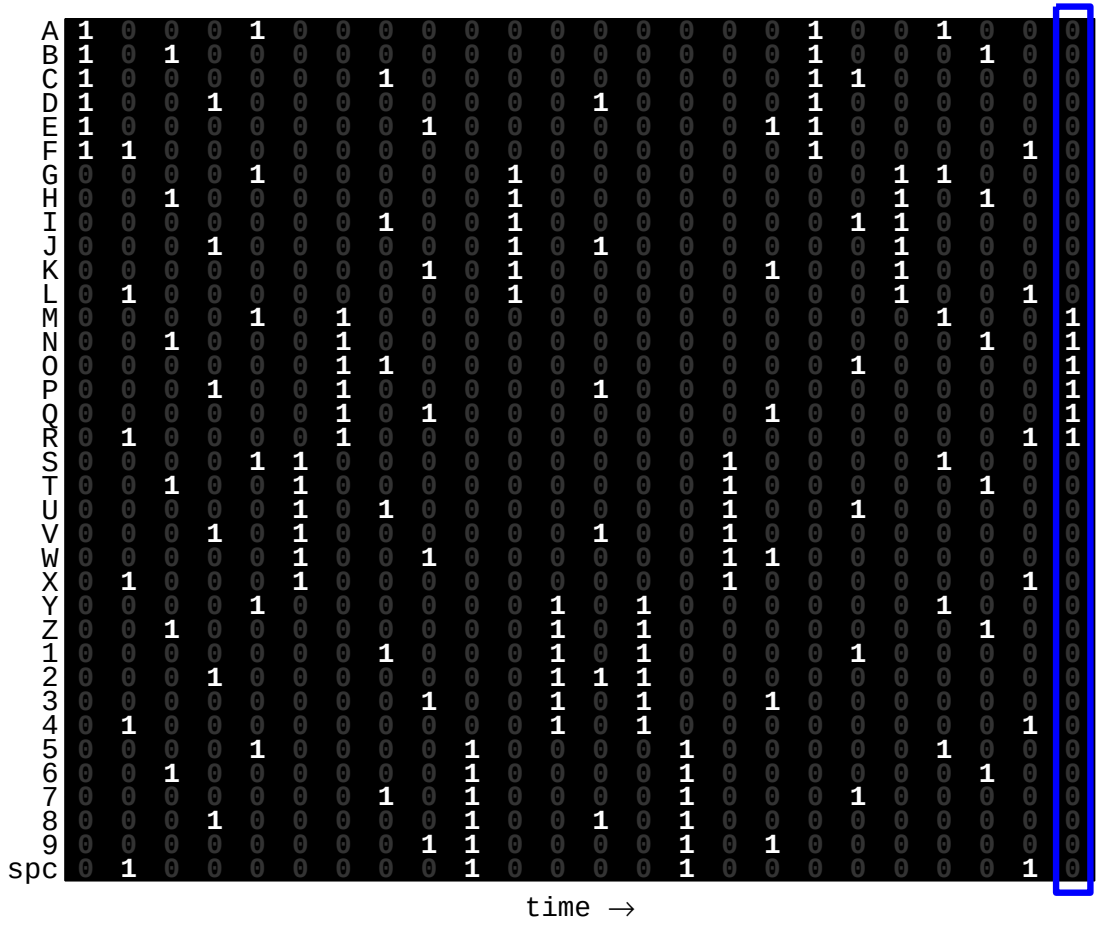

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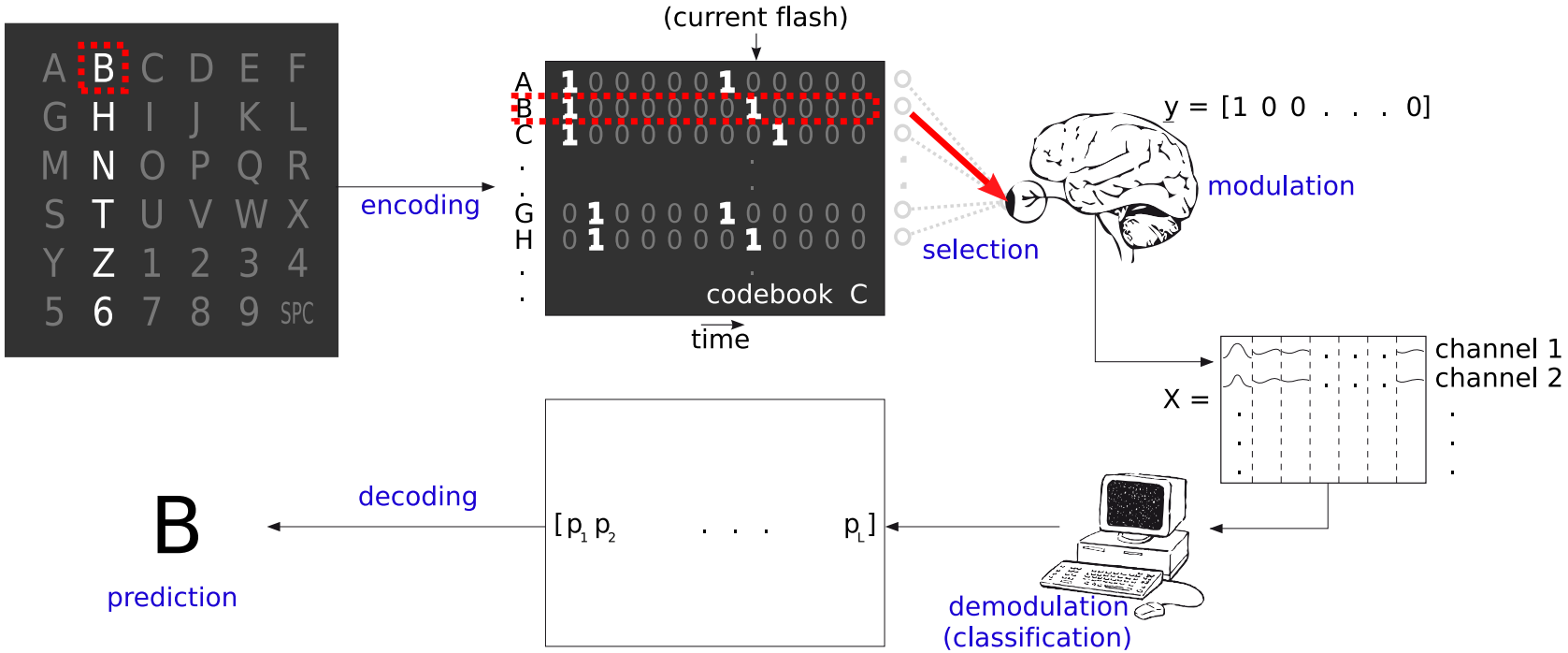

figure from Hill et al. 2009
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Terminology

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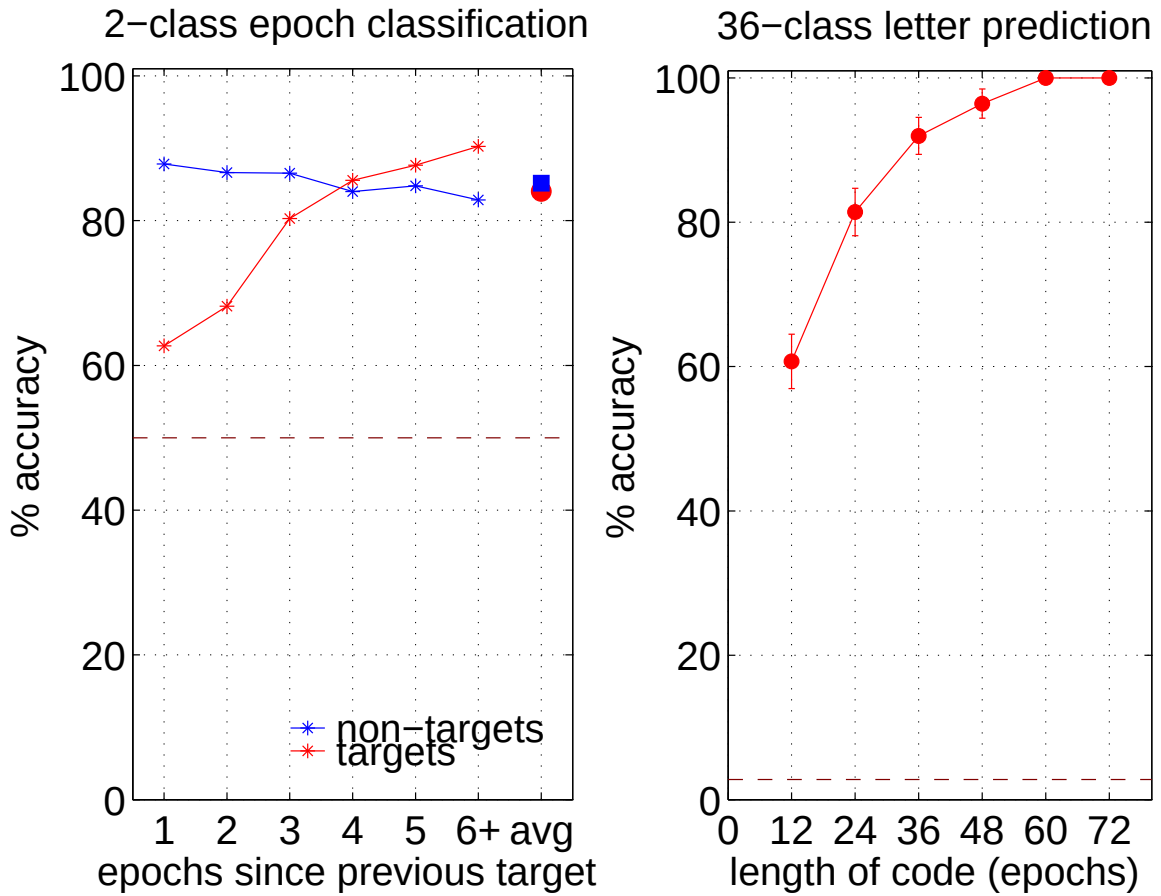
Trial: One attempt to transmit a letter or symbol. Single ERPs, and hence single subtrials, can rarely be classified perfectly, so a trial often consists of multiple subtrials (error-correction by repetition).

From Single ERPs to Symbol Prediction



Data from Hill et al. 2009,
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- Would the system suffer interference from the evoked potentials caused by whatever the user *is* fixating?

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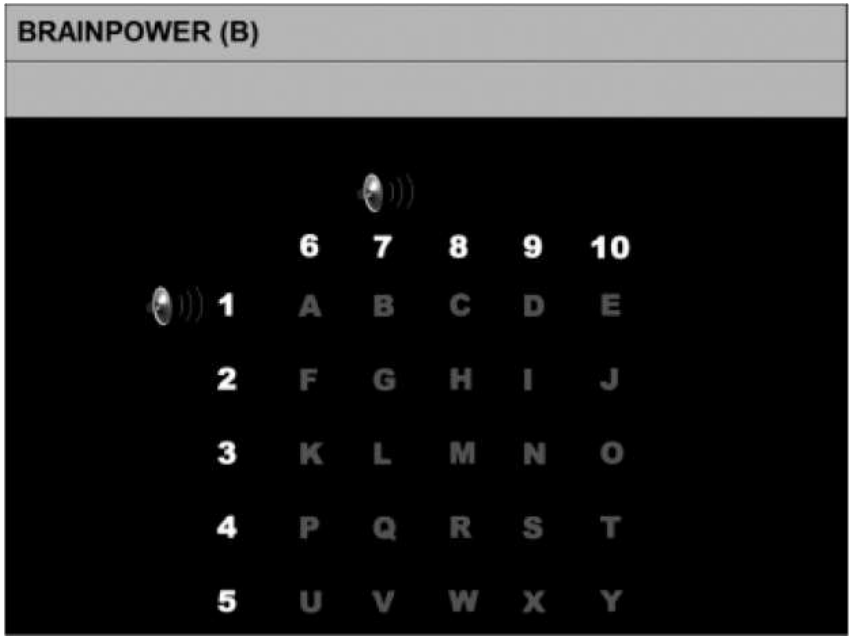
- Would the system suffer interference from the evoked potentials caused by whatever the user *is* fixating?

For anyone:

- Artefacts time-locked to the stimulus of interest will also lead to "successful" BCI performance.

An Auditory P300 Speller

Furdea et al. 2009, Psychophysiology:
Auditorily-presented numbers encode the rows and columns.



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- Stimulus type (Martens et al. 2009, Journal of Neural Engineering)

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The most closely studied of these is the Farwell-Donchin speller, exploiting the user's (overt and covert) attention to one out of a set of visual stimuli.