WINDOWING, SMOOTHING, FILTERING . . . CONVOLUTION!

YU / HUGHES

OCTOBER 05, 2021

UMASS AMHERST

FO DETECTION

WAYS TO ESTIMATE F0: REVIEW QUESTION

- Download this WAV file.

https://drive.google.com/open?id=0BxrcL0TA8FhYY2V3SWdlZjA4UVE

- Estimate the f0 in the two [ma] syllables in three ways. Make TextGrids to segment out each [ma] syllable.

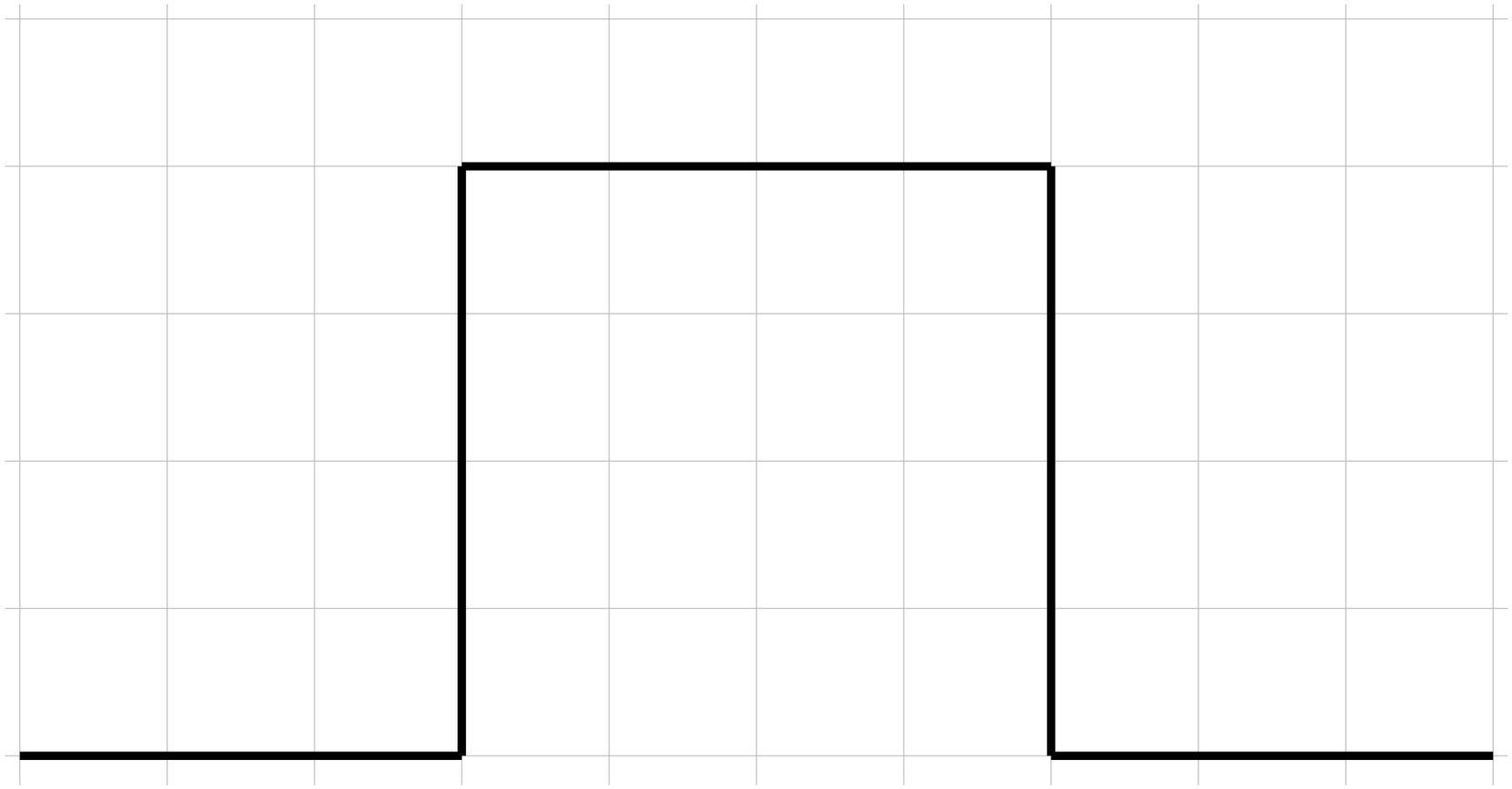
- Measurement methods
  - Off of the waveform: based on cycle-to-cycle distance
  - Off of the spectrum: spacing between harmonics
  - Off of the narrow-band spectrogram

WAYS TO ESTIMATE F0

- **Measurement methods**
  - Off of the waveform: based on cycle-to-cycle distance
  - Off of the spectrum: spacing between harmonics
  - Off of the narrow-band spectrogram (demo)

Note these all involve visual inspection!
How does a computer "see" f0?

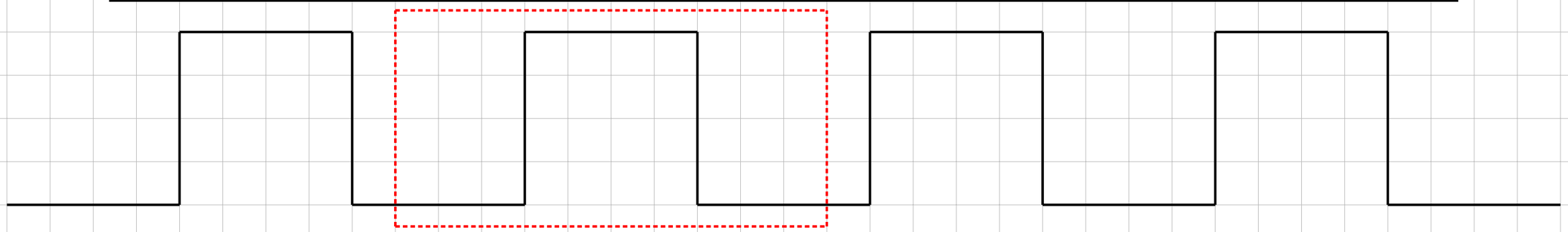
PRAAT F0 DETECTION EXERCISE



One cycle of a “square” wave

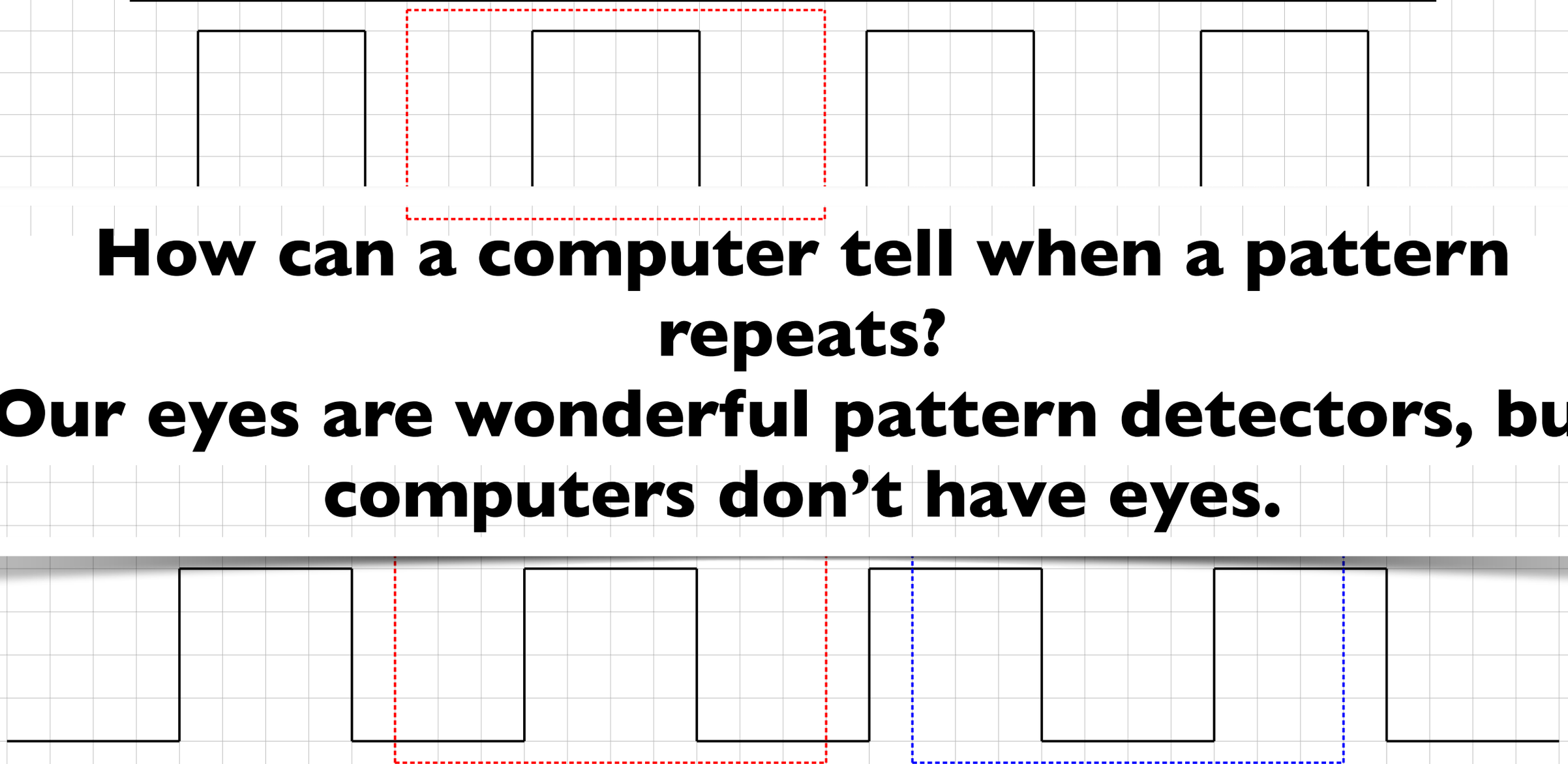
PRAAT F0 DETECTION EXERCISE

What's the period of this waveform?



PRAAT F0 DETECTION EXERCISE

What's the period of this waveform?

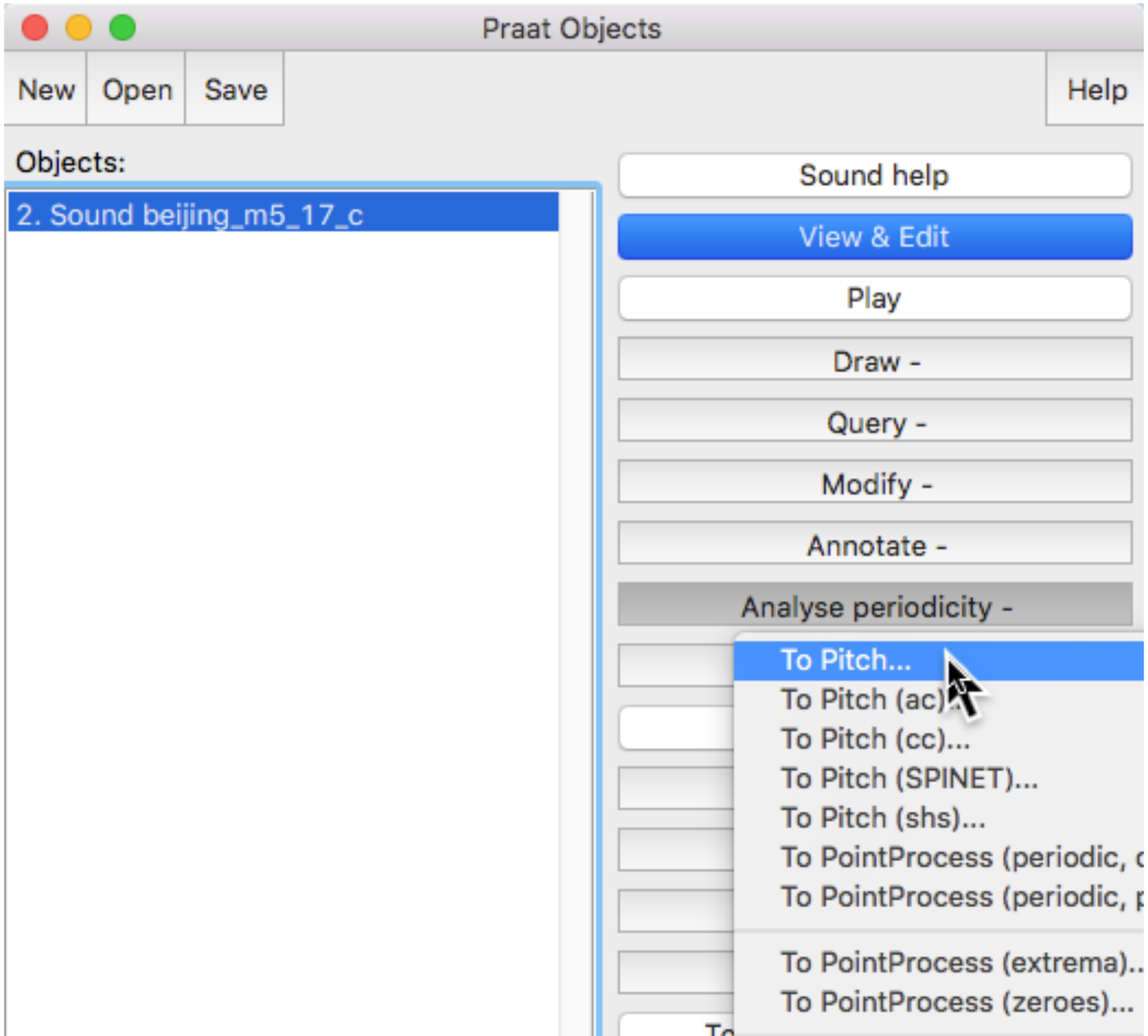


How can a computer tell when a pattern repeats?

Our eyes are wonderful pattern detectors, but computers don't have eyes.

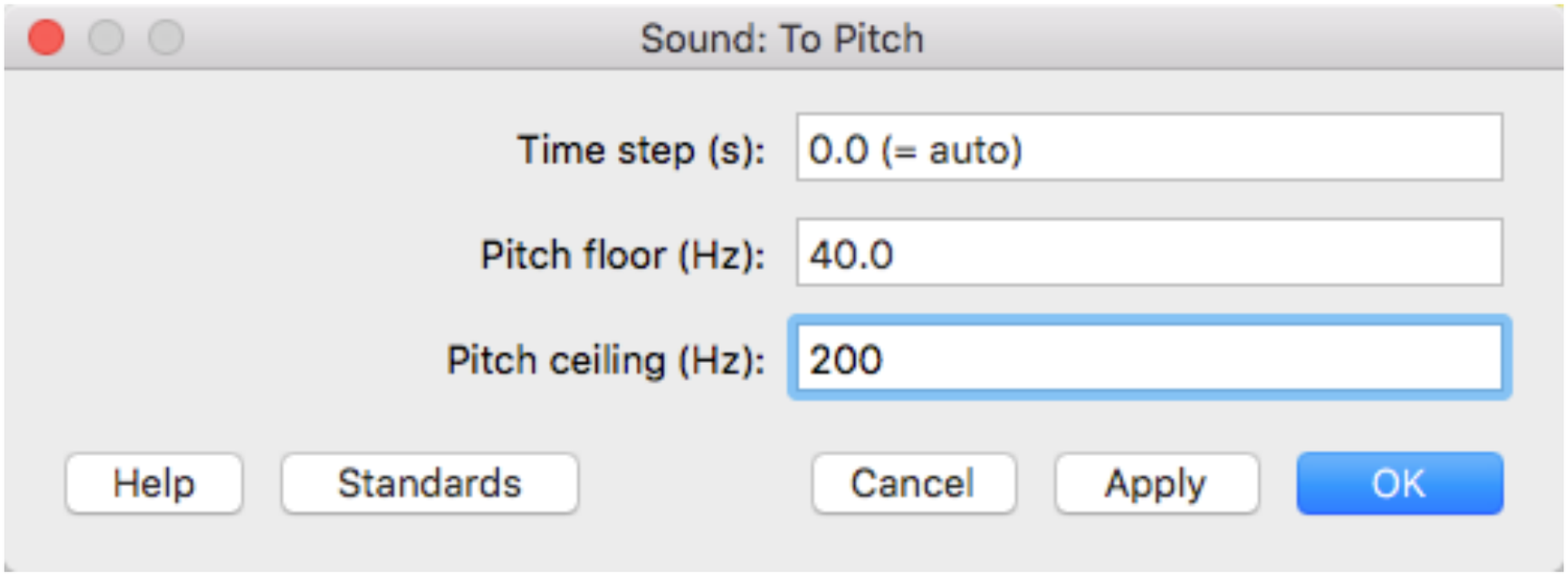
WHAT CAN GO WRONG WITH F0 DETECTION?

- **Create "pitch object" in Praat**



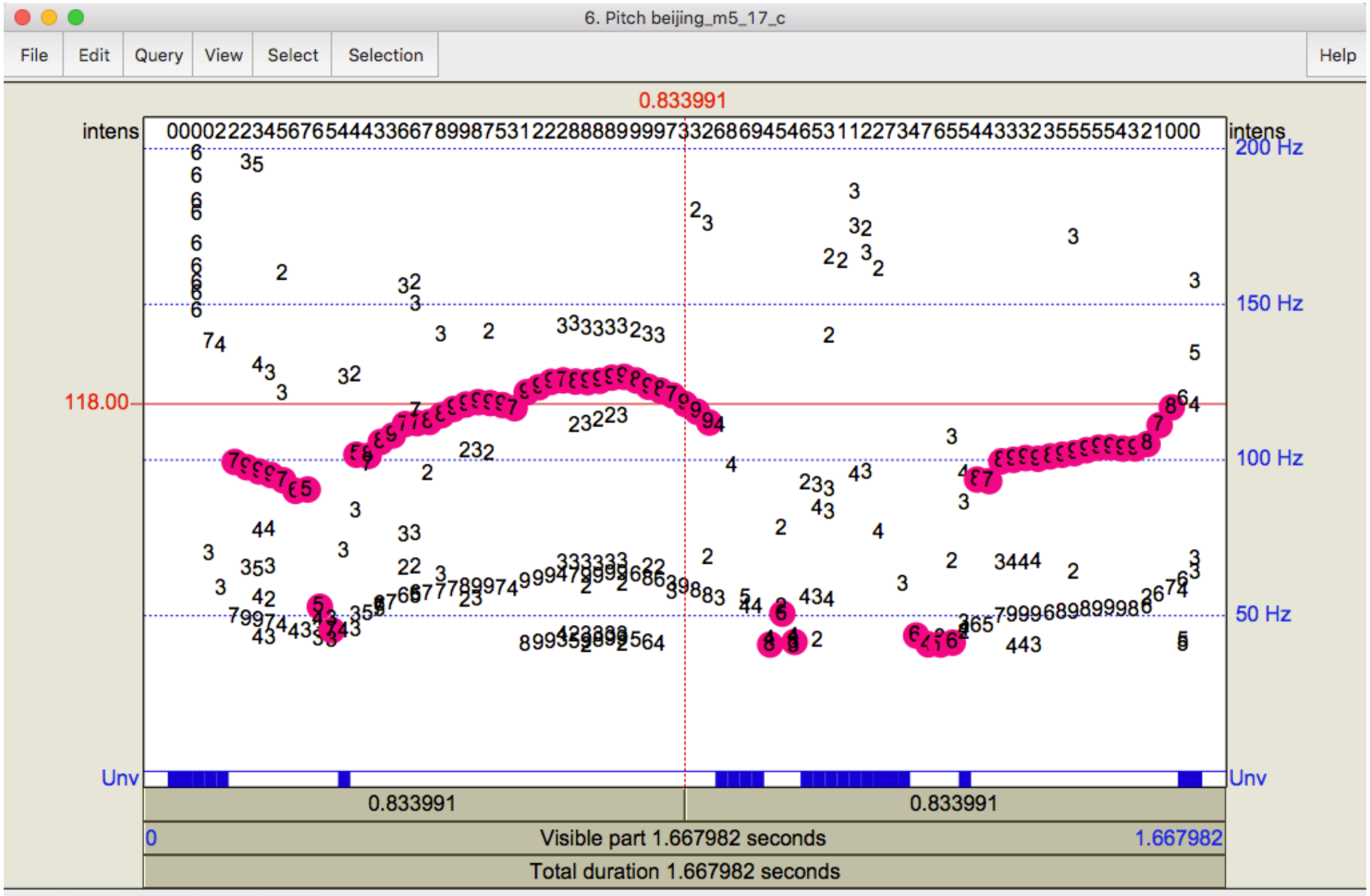
WHAT CAN GO WRONG WITH F0 DETECTION?

- **Select appropriate lower and upper bounds for what f0 values Praat should consider as possible candidates**
  - To investigate creak, drop pitch floor to 40 Hz
  - Pitch ceiling: depends on pitch range of speaker

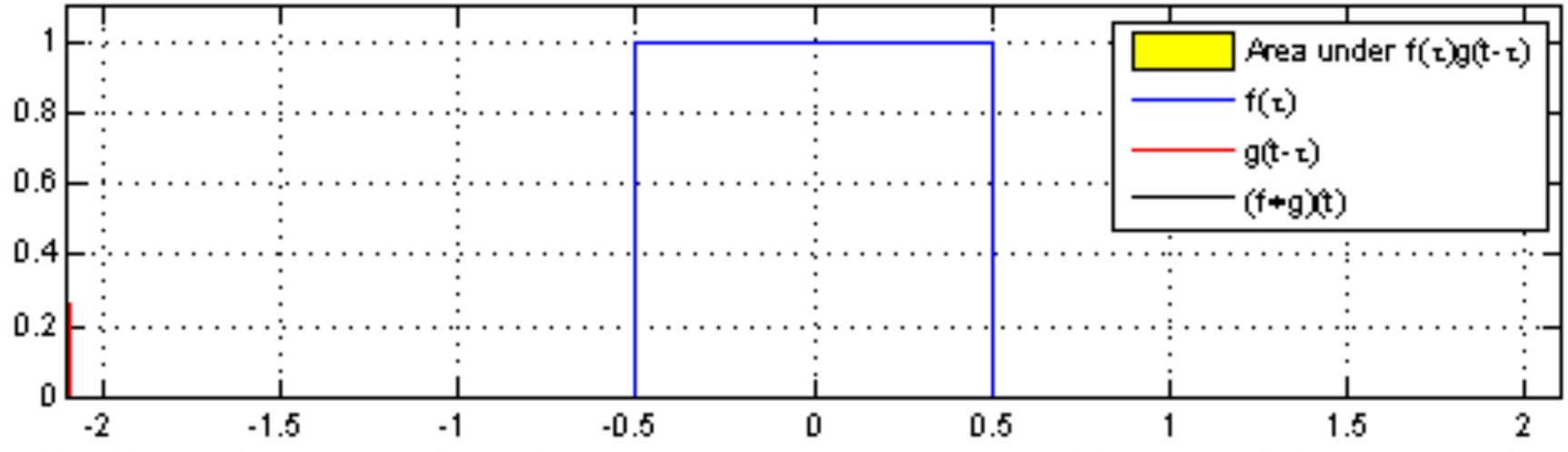


WHAT CAN GO WRONG WITH F0 DETECTION?

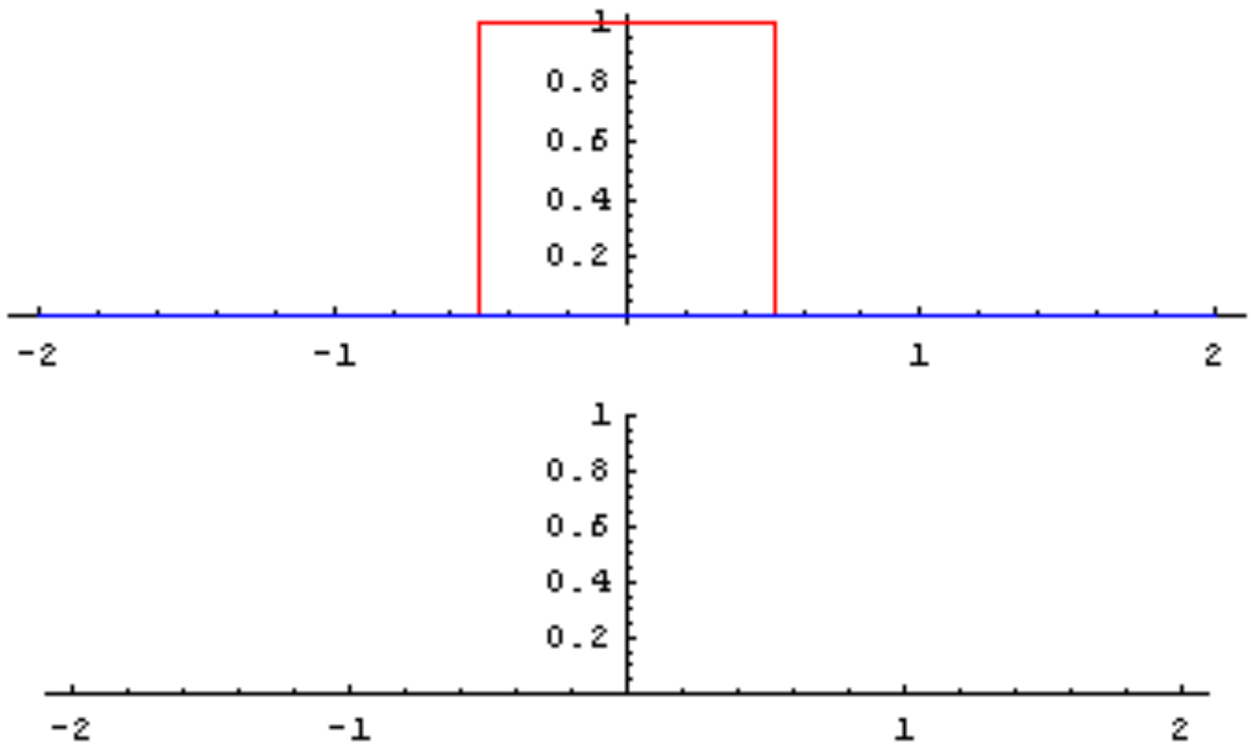
- **Explore the Pitch object**



AUTOCORRELATION



https://upload.wikimedia.org/wikipedia/commons/6/6e/Convolution_of_box_signal_with_itself.gif



https://commons.wikimedia.org/wiki/Category:Convolution#/media/File:Convolucion_Funcion_Pi.gif

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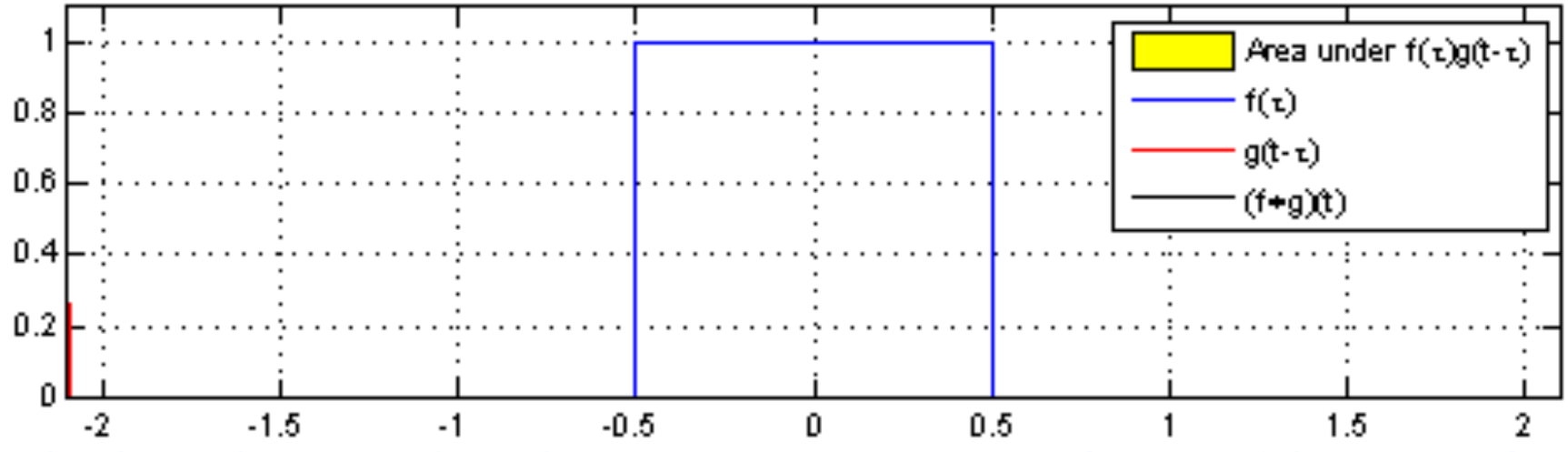

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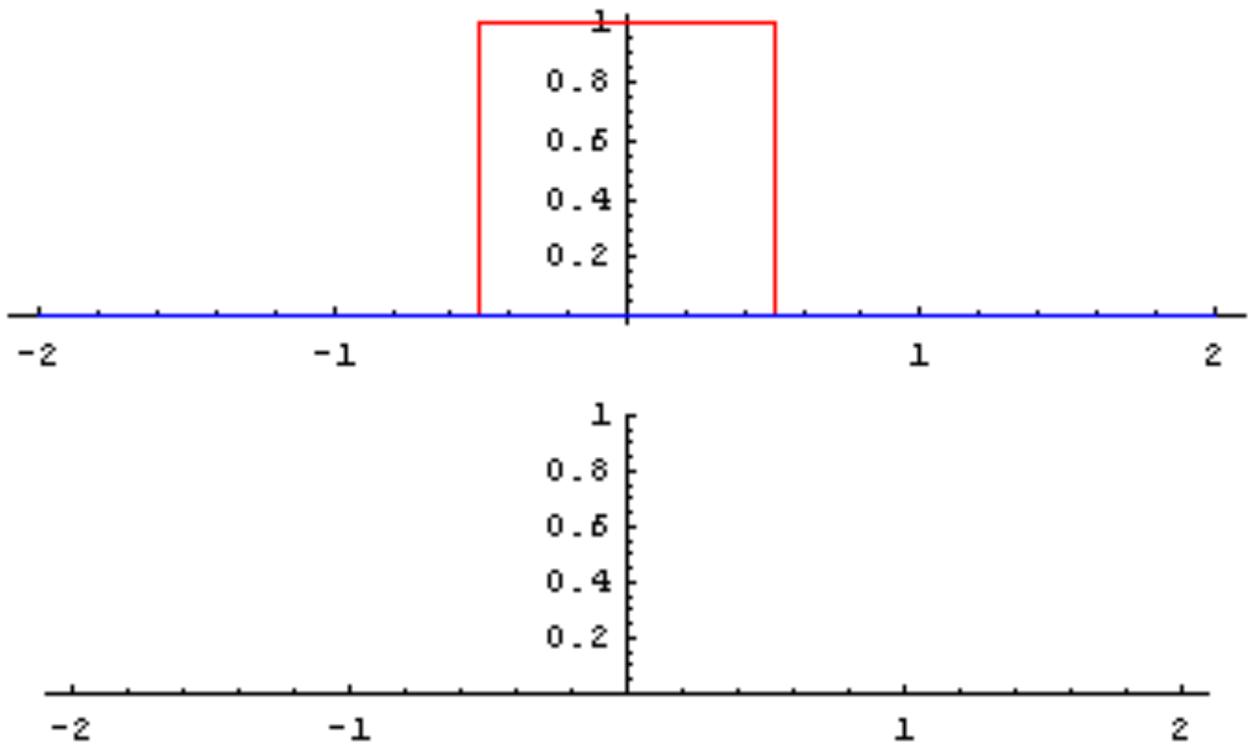

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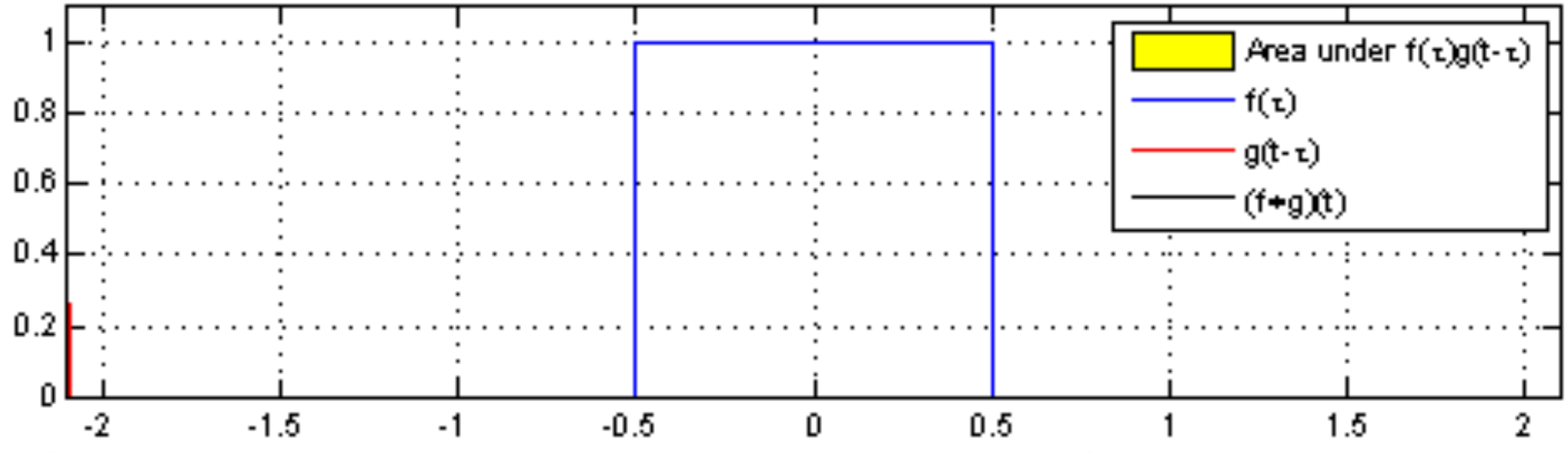

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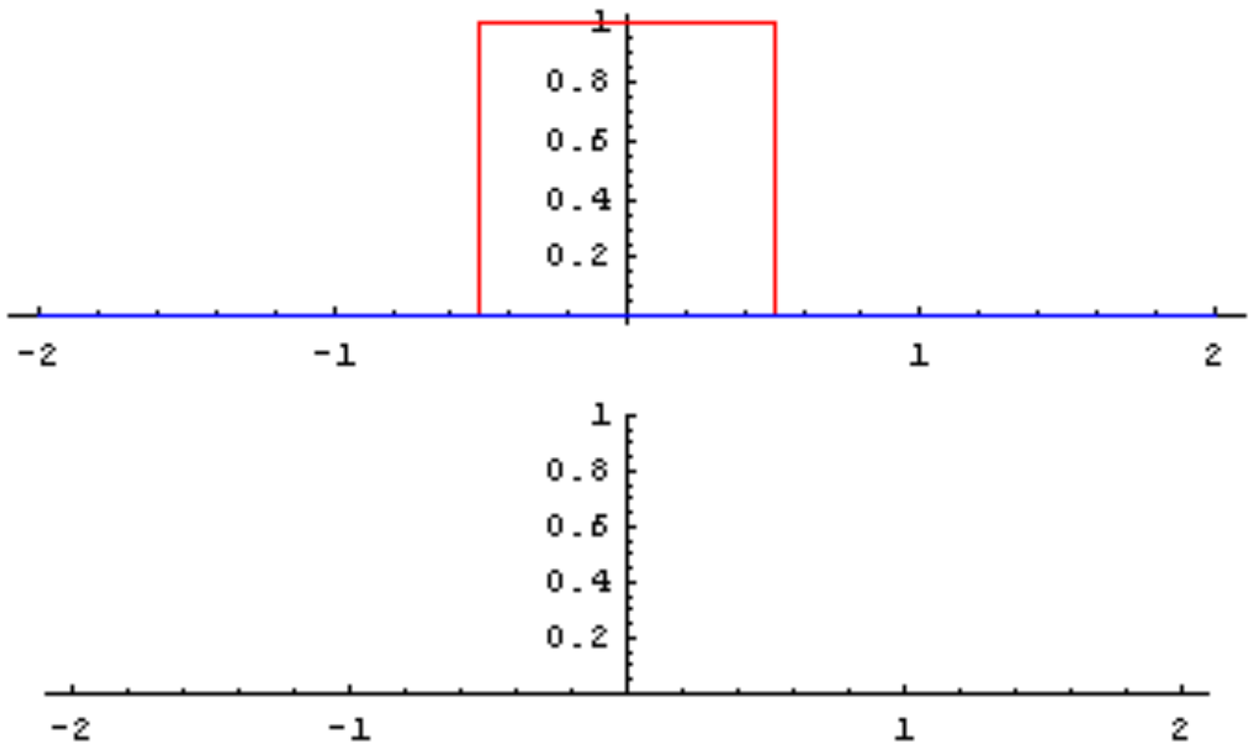

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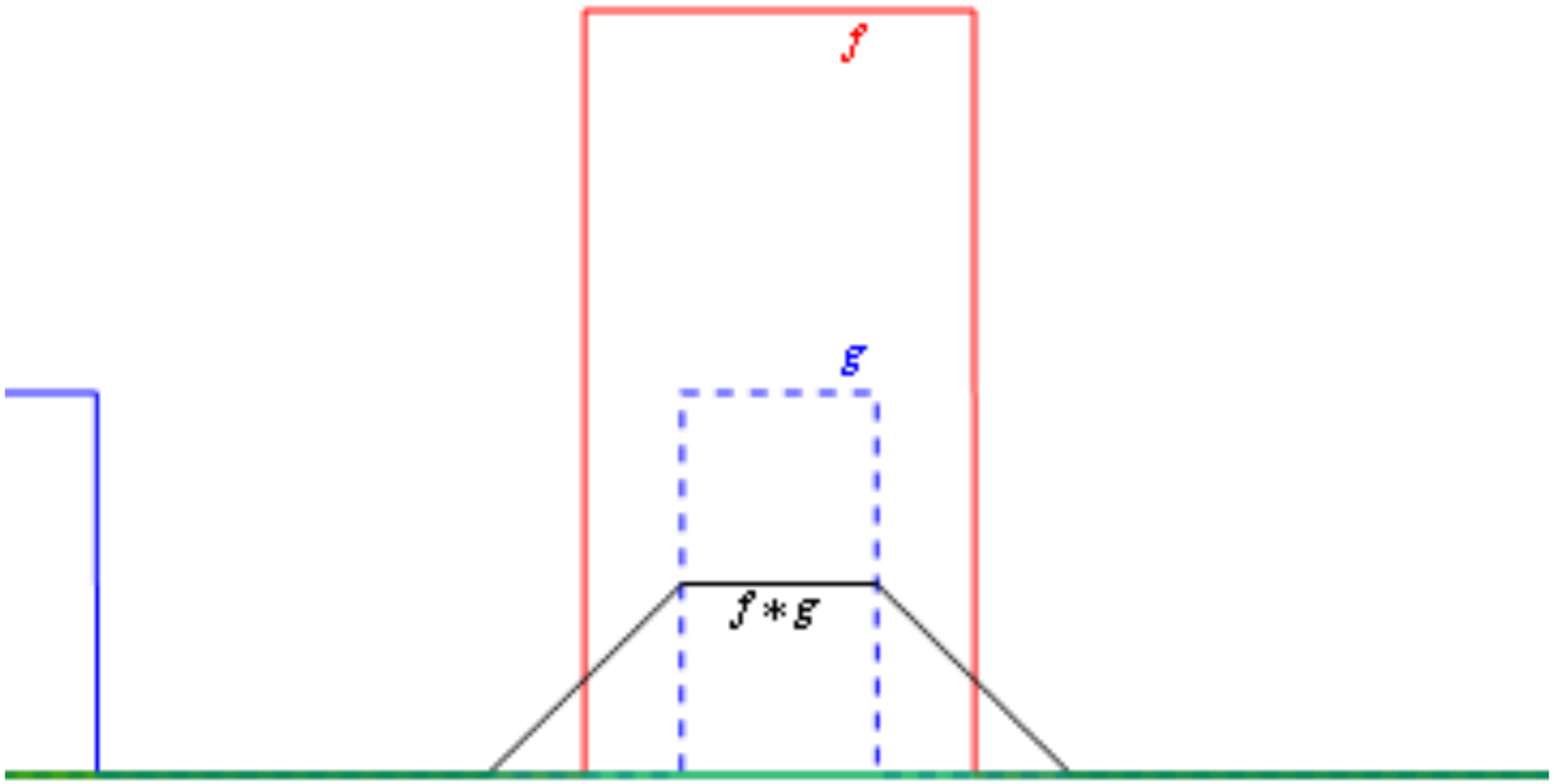
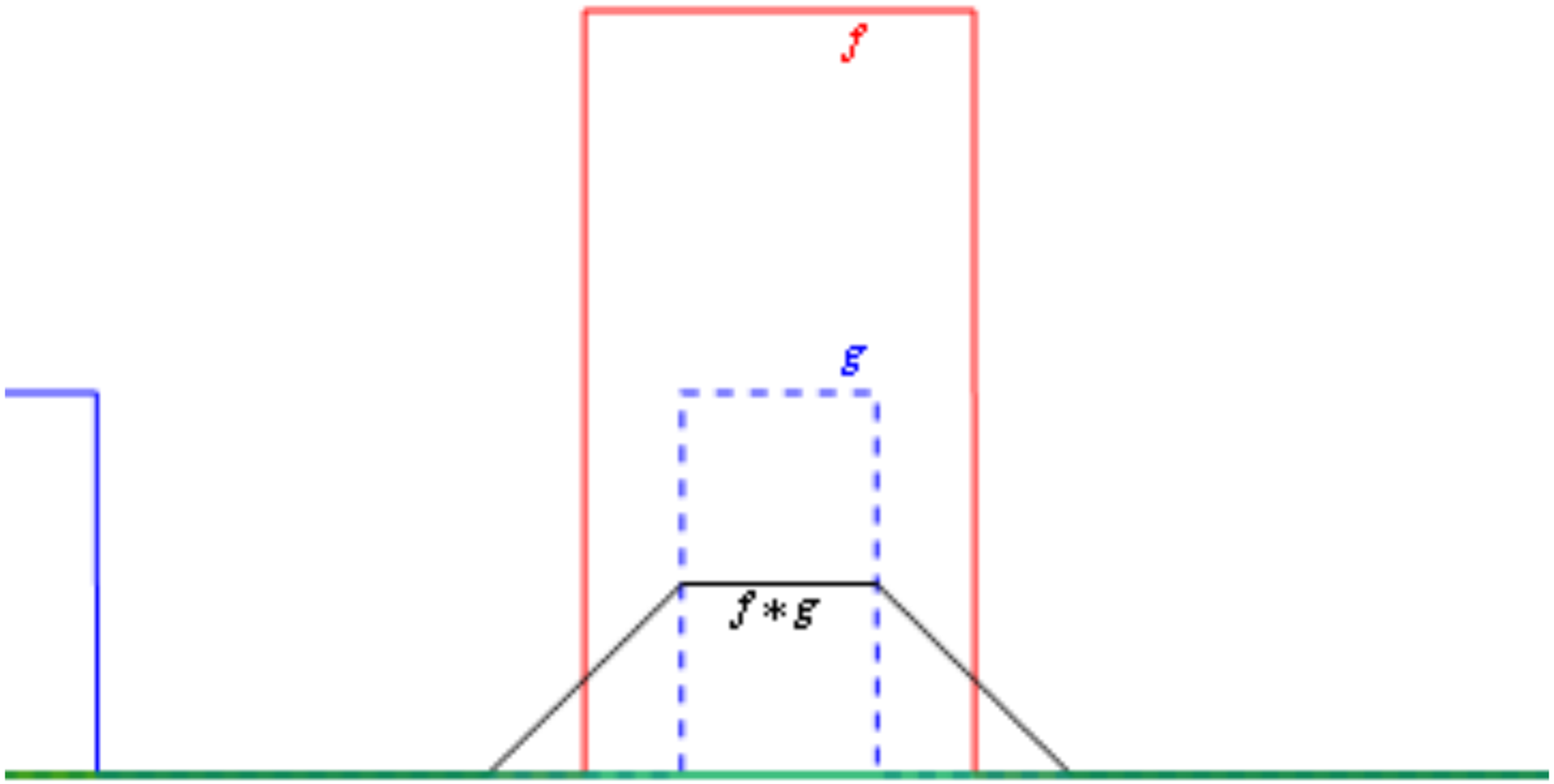
TWO DIFFERENT BOXCARS . . .



https://upload.wikimedia.org/wikipedia/commons/9/97/Convolution_Animation_%28Boxcar%29.gif

TWO DIFFERENT BOXCARS . . .



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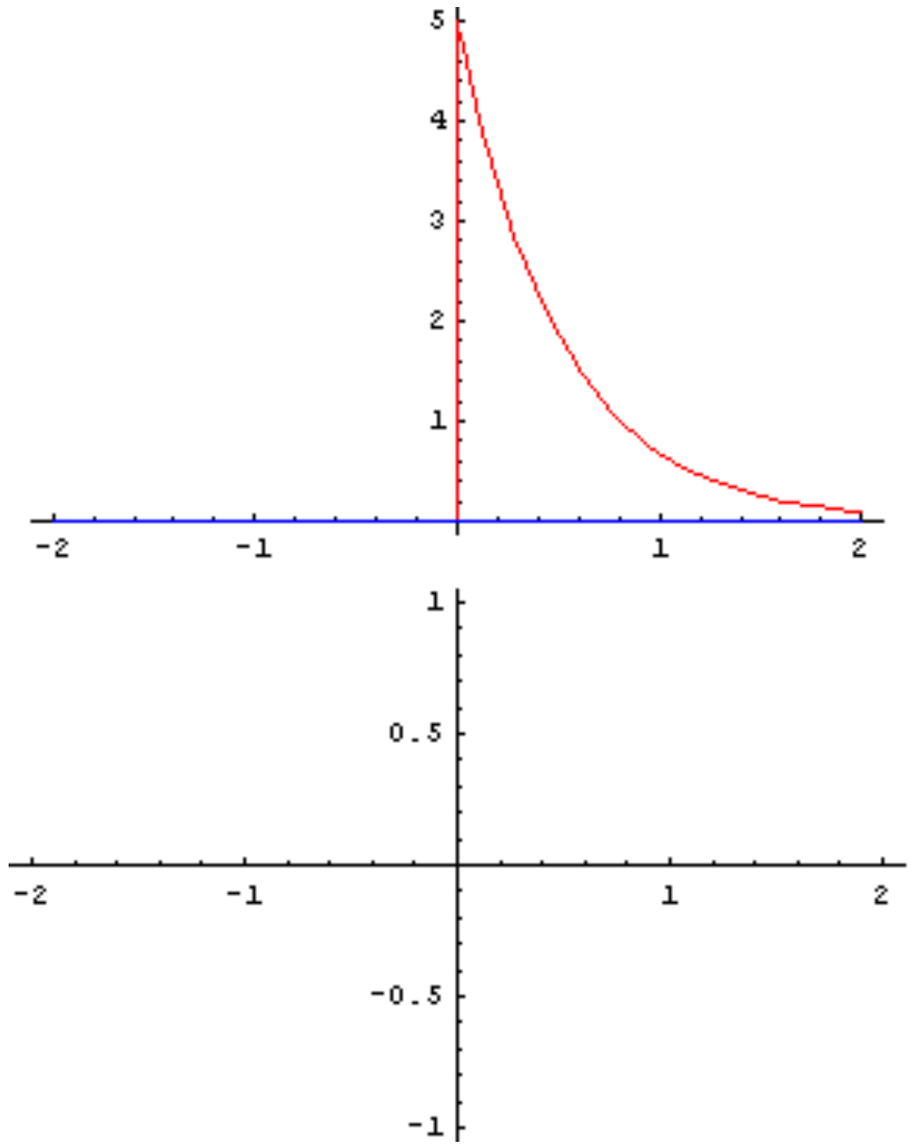
A BOX AND A SPIKY FUNCTION



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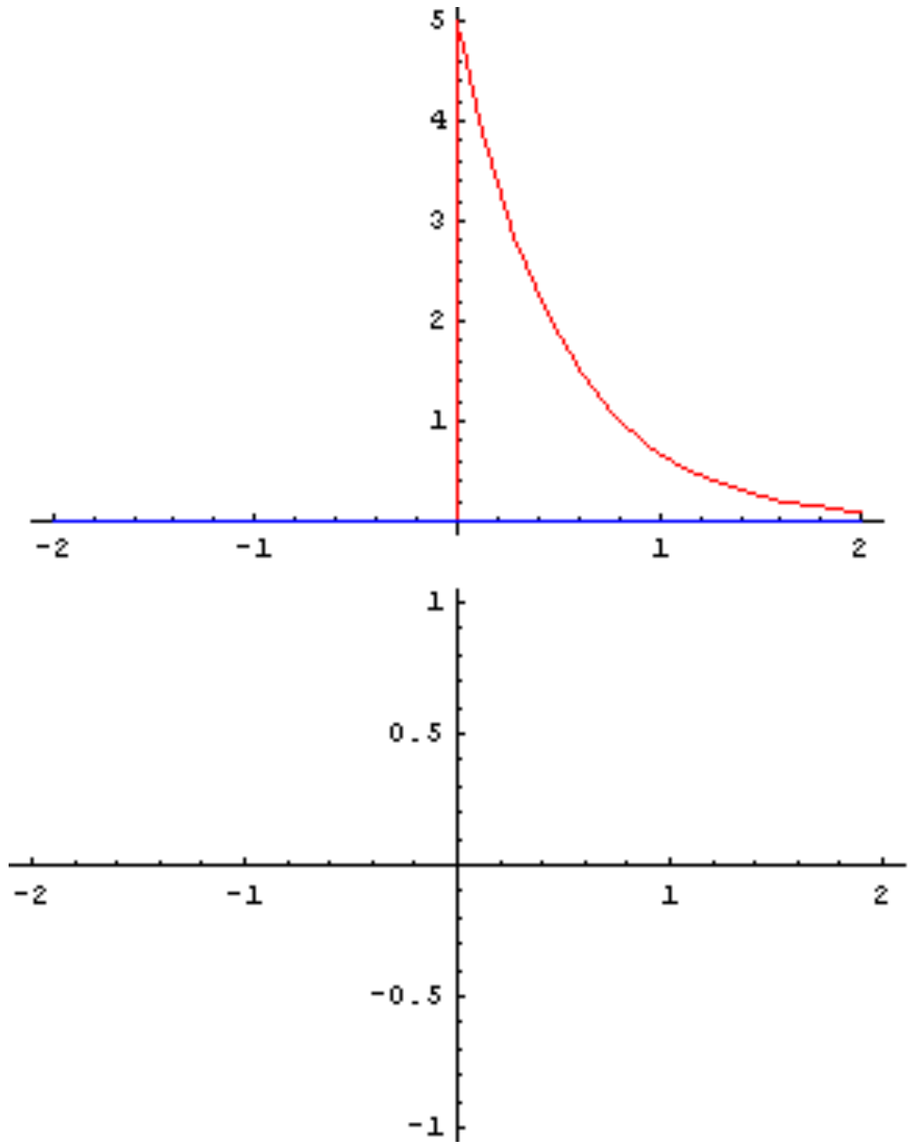

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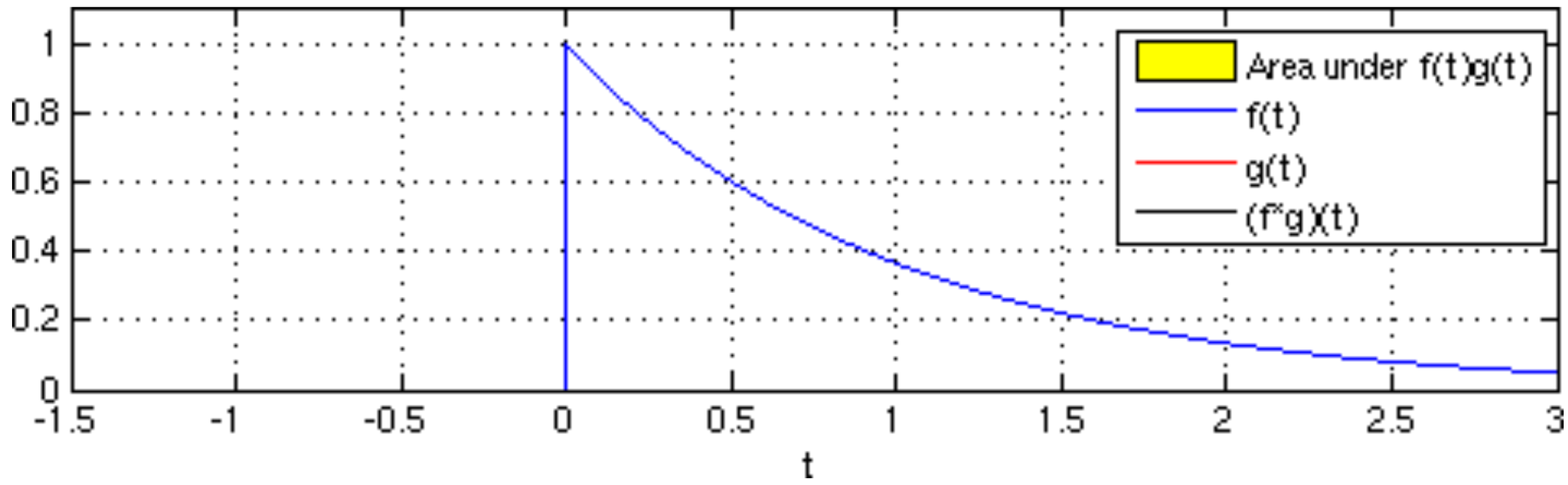
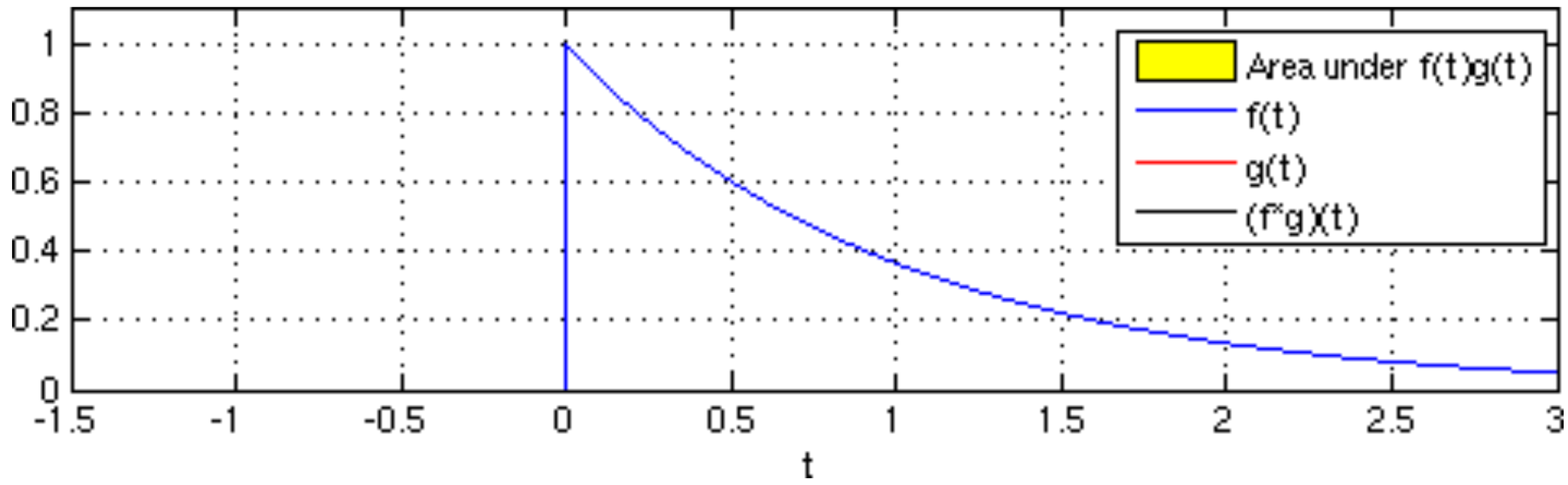


https://upload.wikimedia.org/wikipedia/commons/6/67/Convolution_of_spiky_function_with_box.gif

A BOX AND A SPIKY FUNCTION



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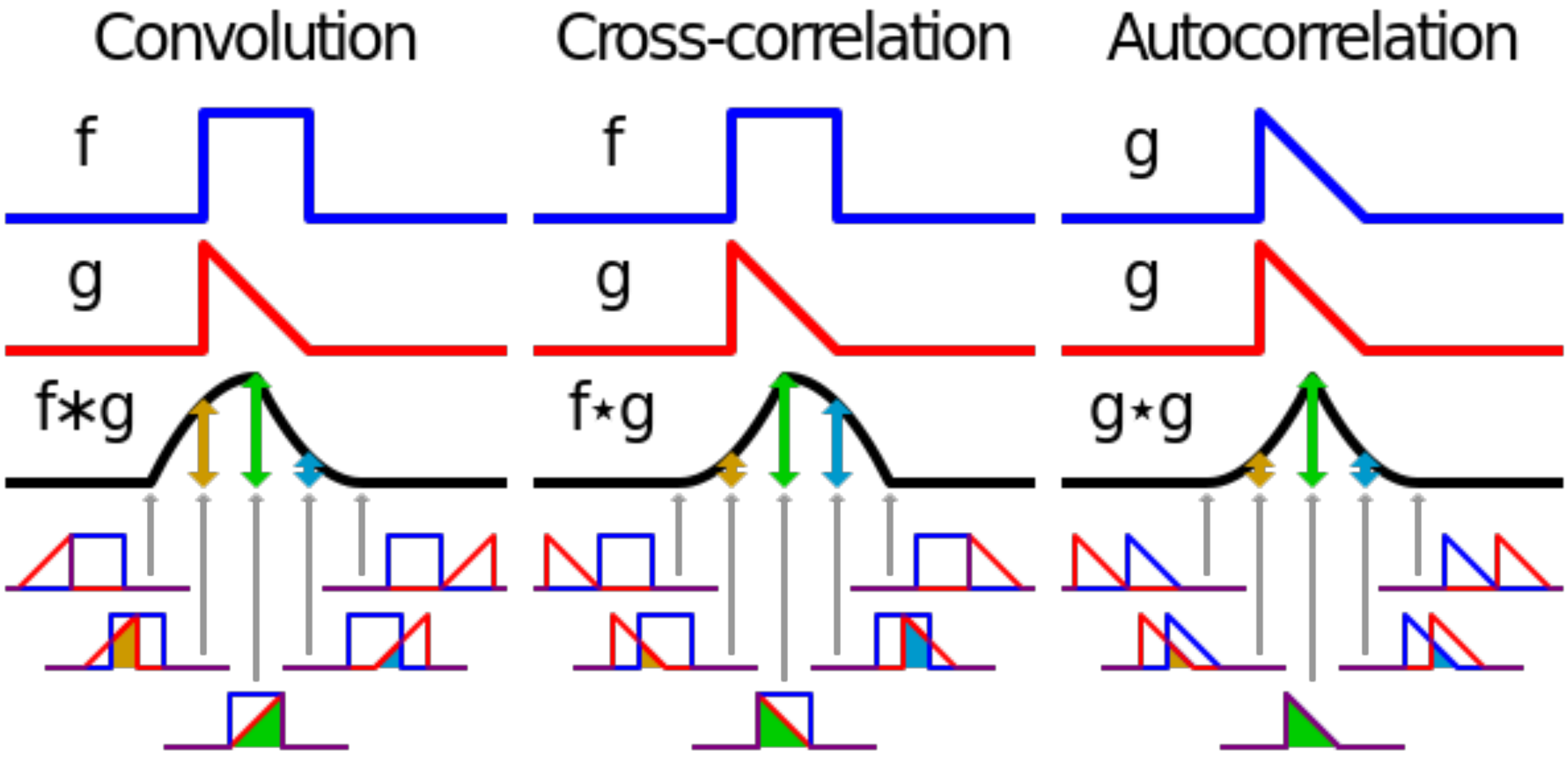
CONVOLUTION

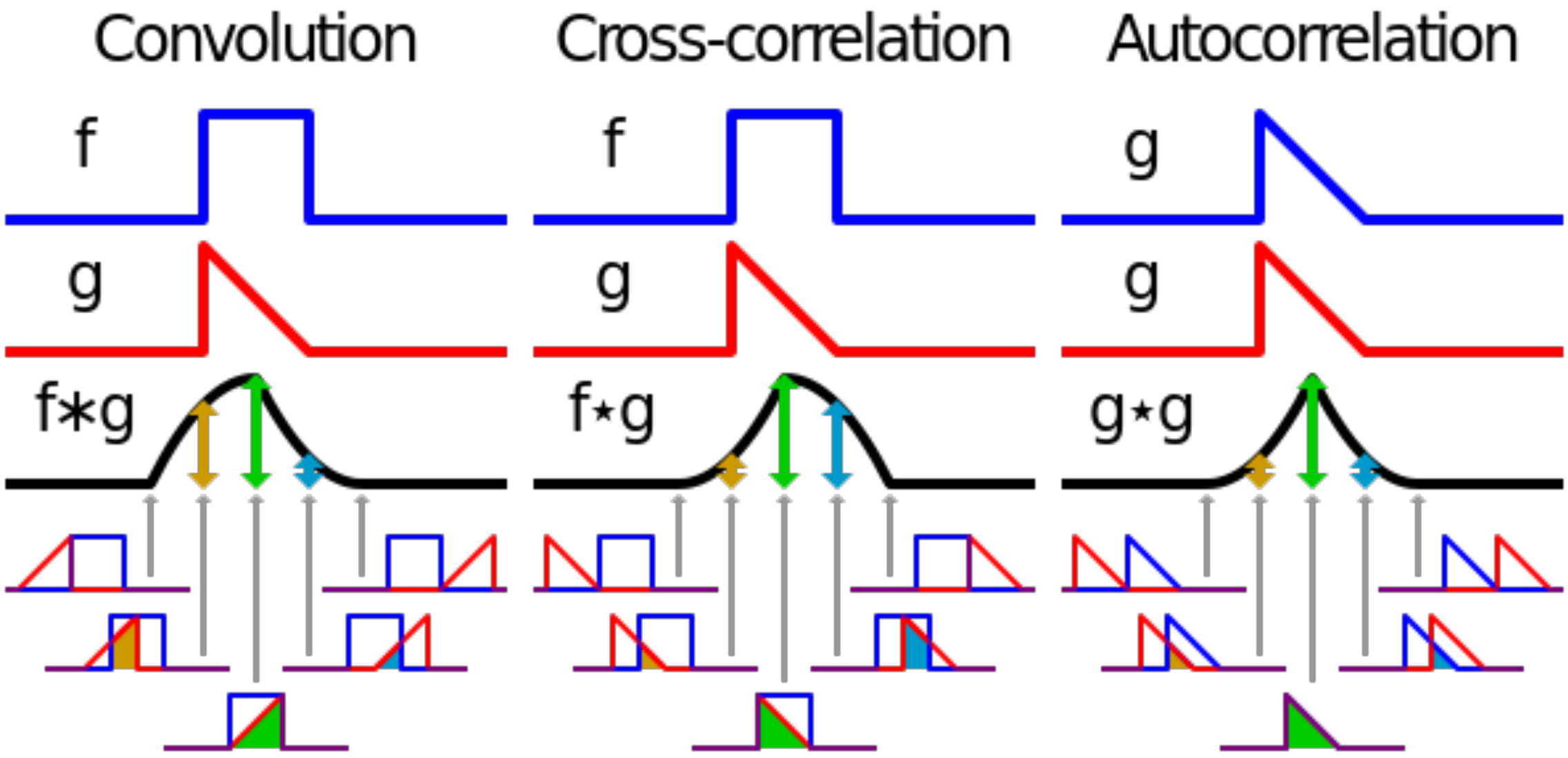
STARS OF DIGITAL SIGNAL PROCESSING



https://dsp.stackexchange.com/questions/27451/the-difference-between-convolution-and-cross-correlation-from-a-signal-analysis

STARS OF DIGITAL SIGNAL PROCESSING

Filtering



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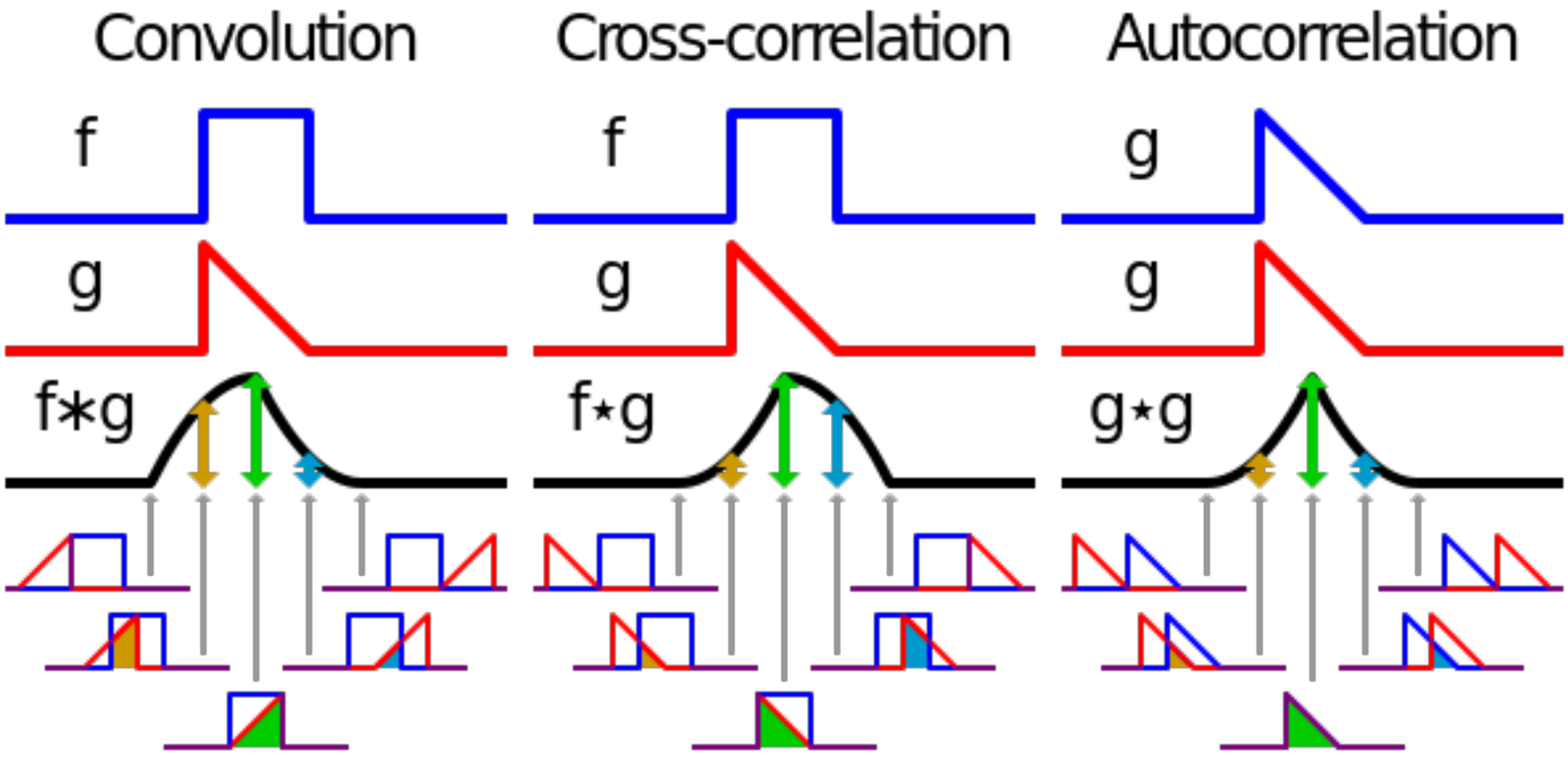
STARS OF DIGITAL SIGNAL PROCESSING

Filtering

Similarity detection



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STARS OF DIGITAL SIGNAL PROCESSING

Convolution

$$f(x) * g(x) \quad = \quad \int_{-\infty}^{\infty} f(\tau) \cdot g(x-\tau)\, d\tau$$

Cross-correlation

$$(f \star g)(t) \stackrel{\text{def}}{=} \int_{-\infty}^{\infty} f^*(\tau)\ g(t+\tau)\, d\tau,$$

https://dsp.stackexchange.com/questions/27451/the-difference-between-convolution-and-cross-correlation-from-a-signal-analysis

WHAT'S WITH THE MINUS SIGN?

https://www.oreilly.com/library/view/elegant-scipy/9781491922927/ch04.html#windowing

The effect of windowing our previous example is noticeable:

```
win = np.kaiser(len(t), 5)
X_win = fftpack.fft(x * win)
```

```
plt.plot(fftpack.fftfreq(len(t)), np.abs(X_win))
plt.ylim(0, 190);
```

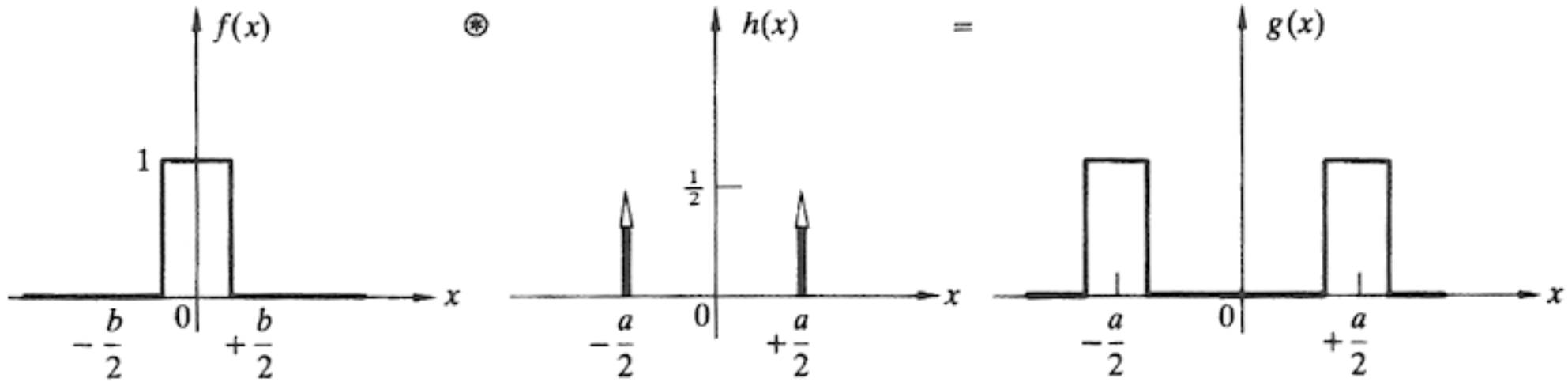
Convolution in time domain

=

Multiplication in frequency domain!

(and vice versa)

HOW IS CONVOLUTION LIKE MULTIPLICATION?



https://www4.uwsp.edu/physastr/kmenning/images/Hecht4.11.F.31.png

FILTERING (OSGOOD NOTES. 3.4.1)

Lowpass filters An ideal *lowpass filter* cuts off all frequencies *above* a certain amount ν_c ("c" for "cutoff") and lets all frequencies *below* ν_c pass through unchanged. (Hence the description "lowpass".) If we write the operation as

$$w(t) = (h * v)(t) \rightleftharpoons W(s) = H(s)V(s)\,,$$

then the transfer function we want is

$$H(s) = \begin{cases} 1 & |s| < \nu_c \\ 0 & |s| \geq \nu_c \end{cases}$$

Multiplying $V(s)$ by $H(s)$ leaves unchanged the spectrum of v for $|s| < \nu_c$ and eliminates the other frequencies. The transfer function is just a scaled rect function, and we can write it (to remind you) as

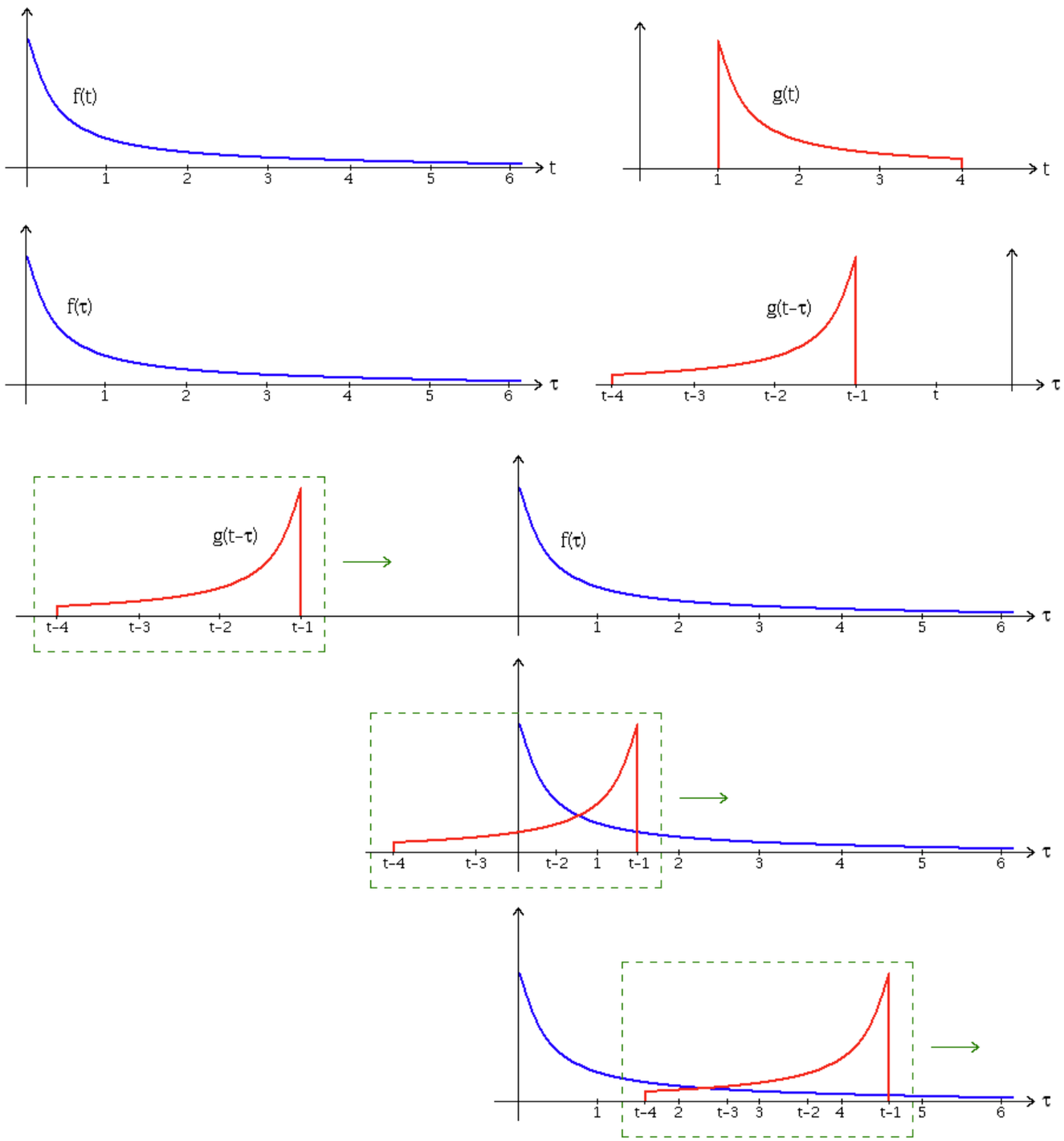
$$H(s) = \Pi_{2\nu_c}(s) = \Pi(s/2\nu_c) = \begin{cases} 1 & |s/2\nu_c| < \frac{1}{2} \\ 0 & |s/2\nu_c| \geq \frac{1}{2} \end{cases} = \begin{cases} 1 & |s| < \nu_c \\ 0 & |s| \geq \nu_c \end{cases}$$

In the time domain the impulse response is the inverse Fourier transform of $\Pi_{2\nu_c}$, and this is

$$h(t) = 2\nu_c \operatorname{sinc}(2\nu_c t)\,.$$

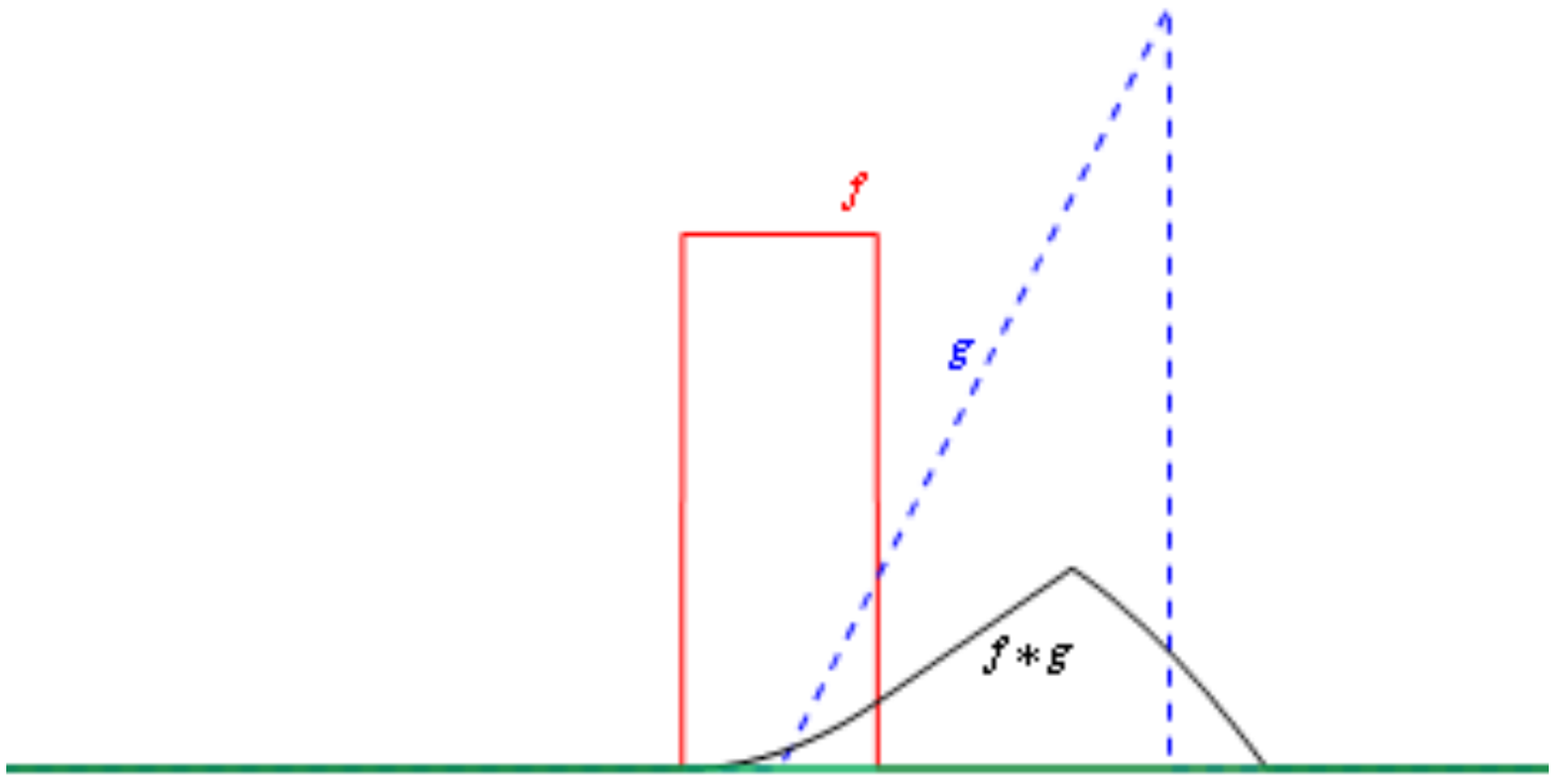
FLIP AND SHIFT!

https://commons.wikimedia.org/wiki/Category:Convolution#/media/File:Convolution3.PNG



FLIP AND SHIFT! RECT AND RAMP

https://upload.wikimedia.org/wikipedia/commons/f/f8/Convolution_Animation_%28Boxcar_and_Ramp%29.gif



FLIP AND SHIFT! RECT AND RAMP

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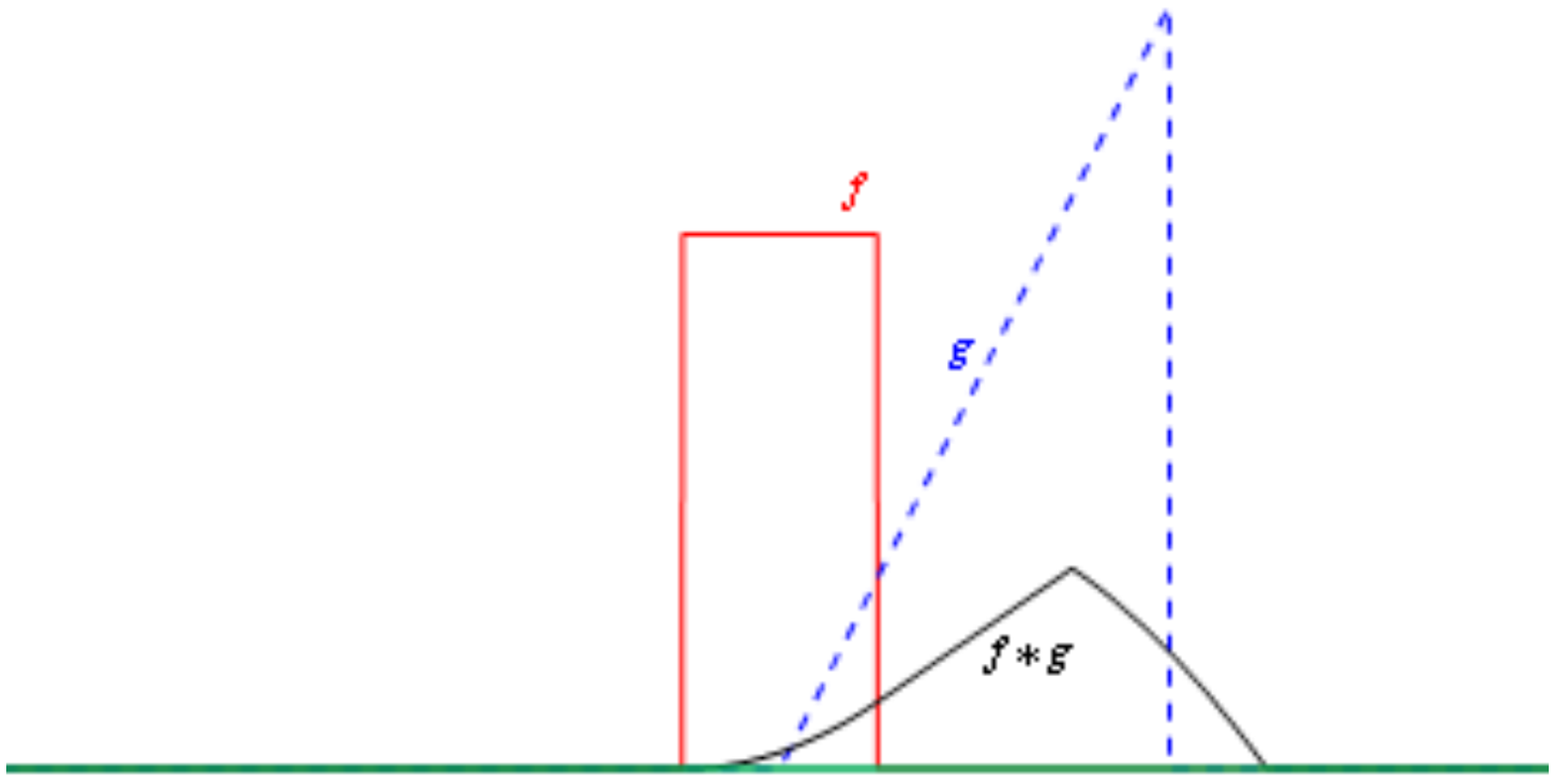

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What happens when you convolve a rect function with itself three times? Four times? Five times? etc.?

****

What happens when you convolve a Gaussian function with some other Gaussian function? three times? Four times? Five times? etc.?

DIGITAL CONVOLUTION

One Way to Think of Convolution

$$x(t) * h(t) = \int_{-\infty}^{\infty} x(\tau)h(t-\tau)d\tau$$

$$x[j] * h[j] = \sum_{k} x[k] \cdot h[j-k]$$

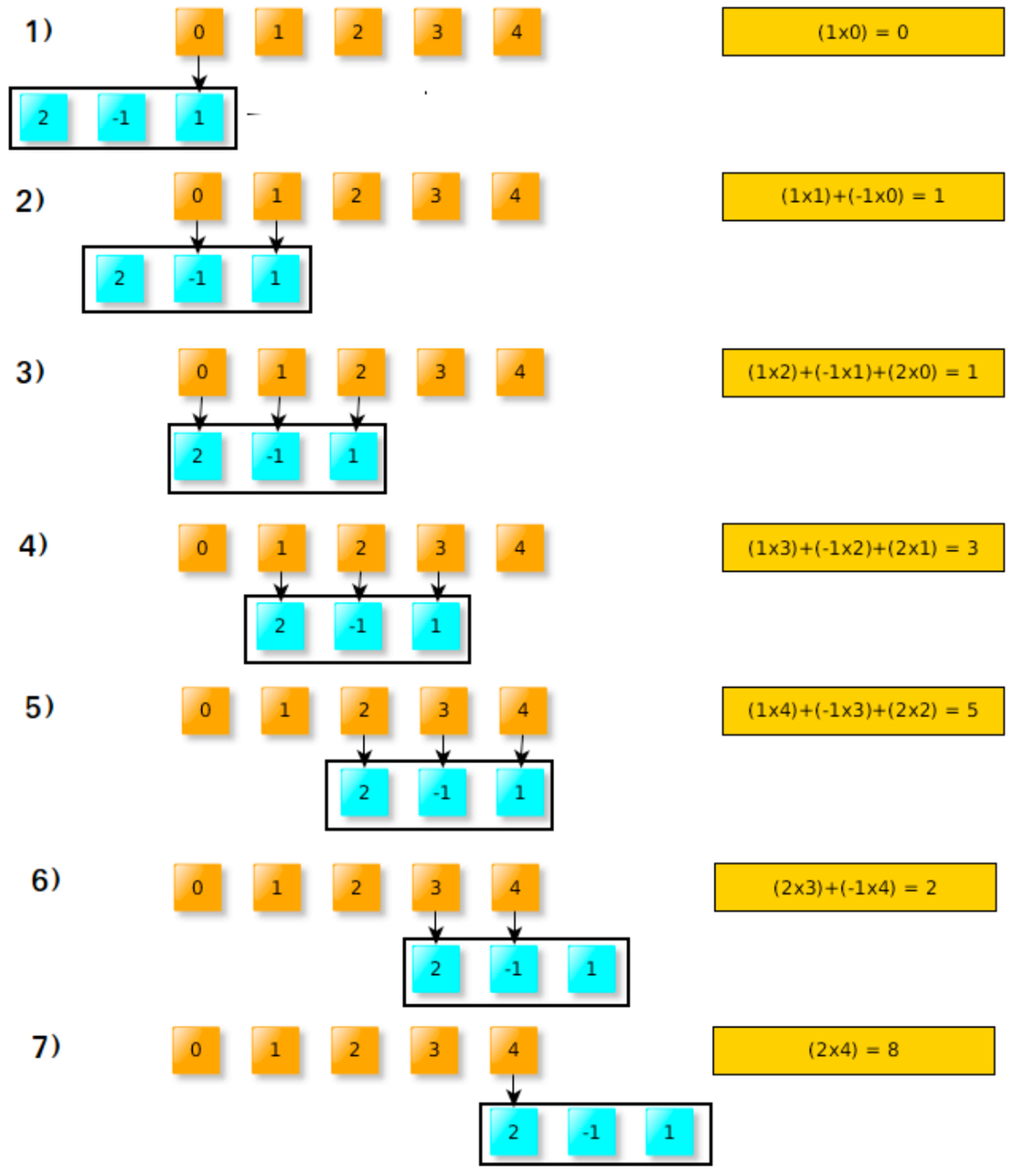
Think of it this way:

- Shift a copy of h to each position t (or discrete position k)
- Multiply by the value at that position $x(t)$ (or discrete sample $x[k]$)
- Add shifted, multiplied copies for all t (or discrete k)

http://situs.biomachina.org/hn06/talks/Baldwin/convolution_filters_new.pdf

FOR A WORKED OUT NUMERICAL EXAMPLE…

https://leonardoaraujosantos.gitbooks.io/artificial-inteligence/content/convolution.html



FOR A WORKED OUT NUMERICAL EXAMPLE...

https://leonardoaraujosantos.gitbooks.io/artificial-inteligence/content/convolution.html

```
In [1]: import numpy as np

In [2]: x = np.array([0,1,2,3,4])

In [3]: w = np.array([1,-1,2])

In [4]: res = np.convolve(x,w)

In [5]: print res
[0 1 1 3 5 2 8]
```