Polar FEC Codes Running at Hundreds of Mbit/s in GNU Radio or On a Software Implementation of the Fast-SSC Algorithm

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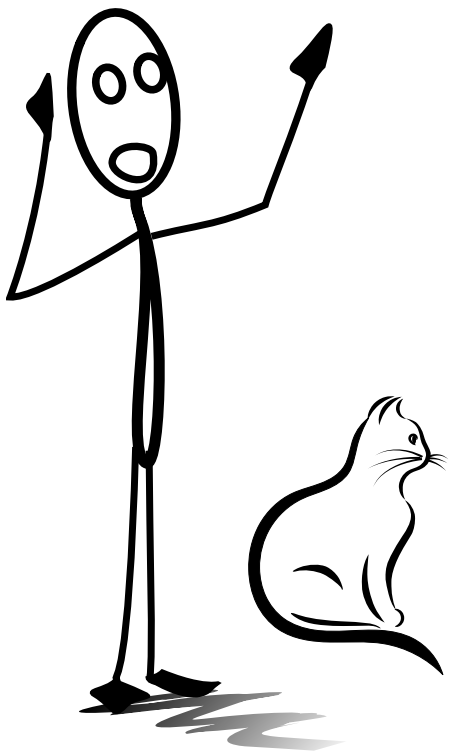
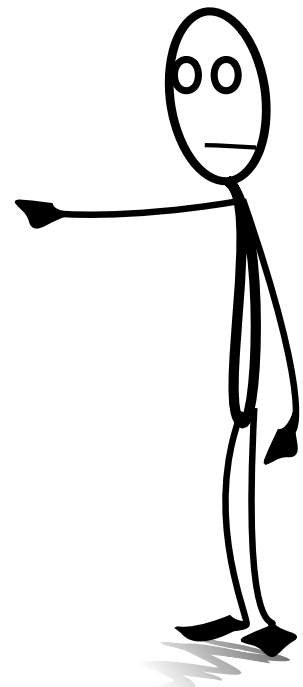
Who am I?

- Ph.D. candidate and research assistant at McGill University.
- Lecturer and research professional at ÉTS.
- Work on efficient algorithms and implementations for modern error-correction codes with a special focus on polar codes.
  - FPGA and ASIC
  - Intel/AMD x86-64 and ARM NEON SIMD
  - GPGPU

Introduction to Error Correction





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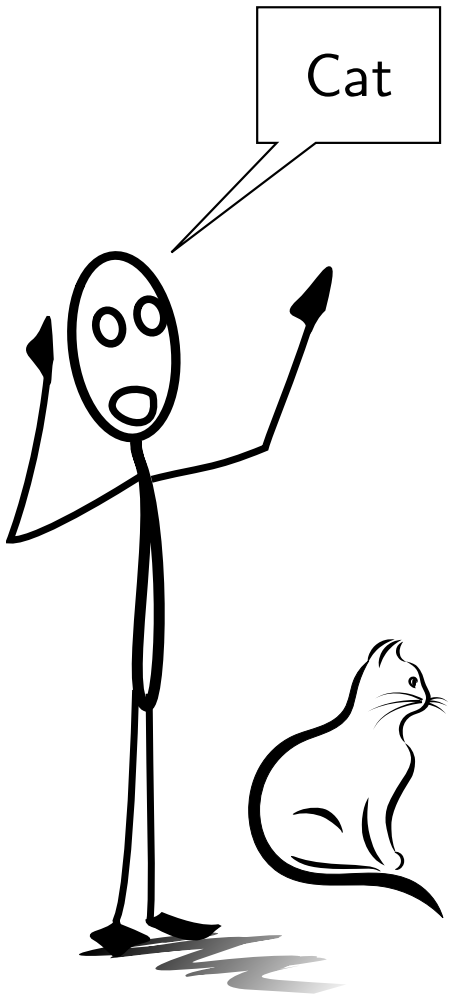

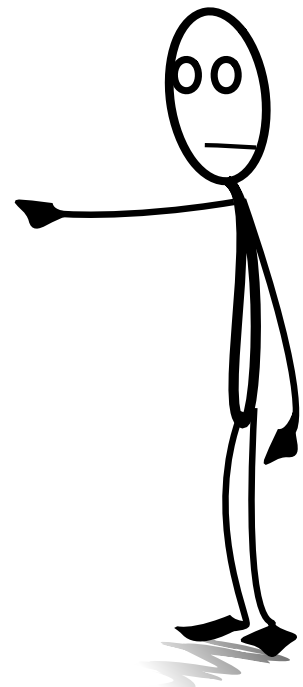

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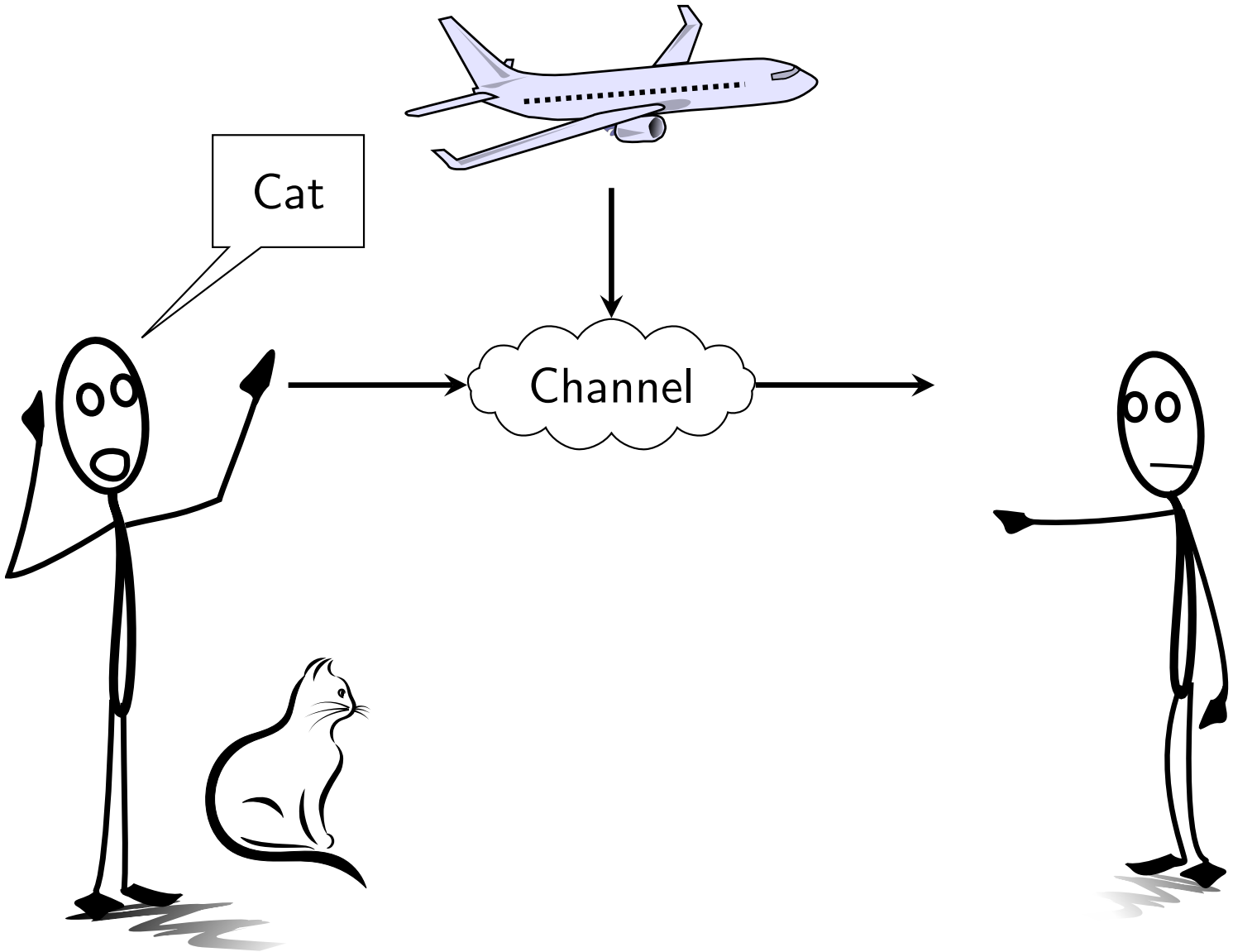

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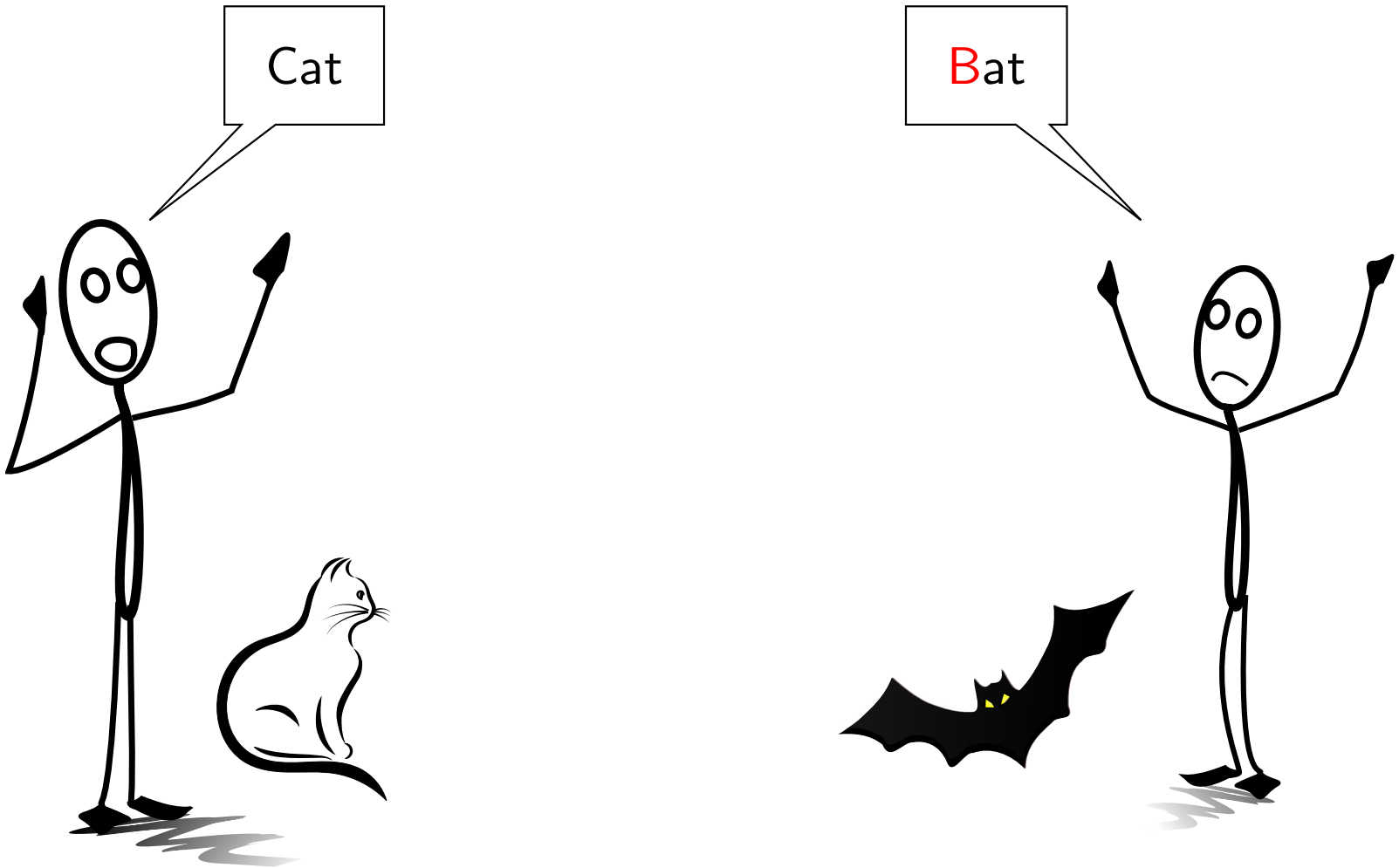

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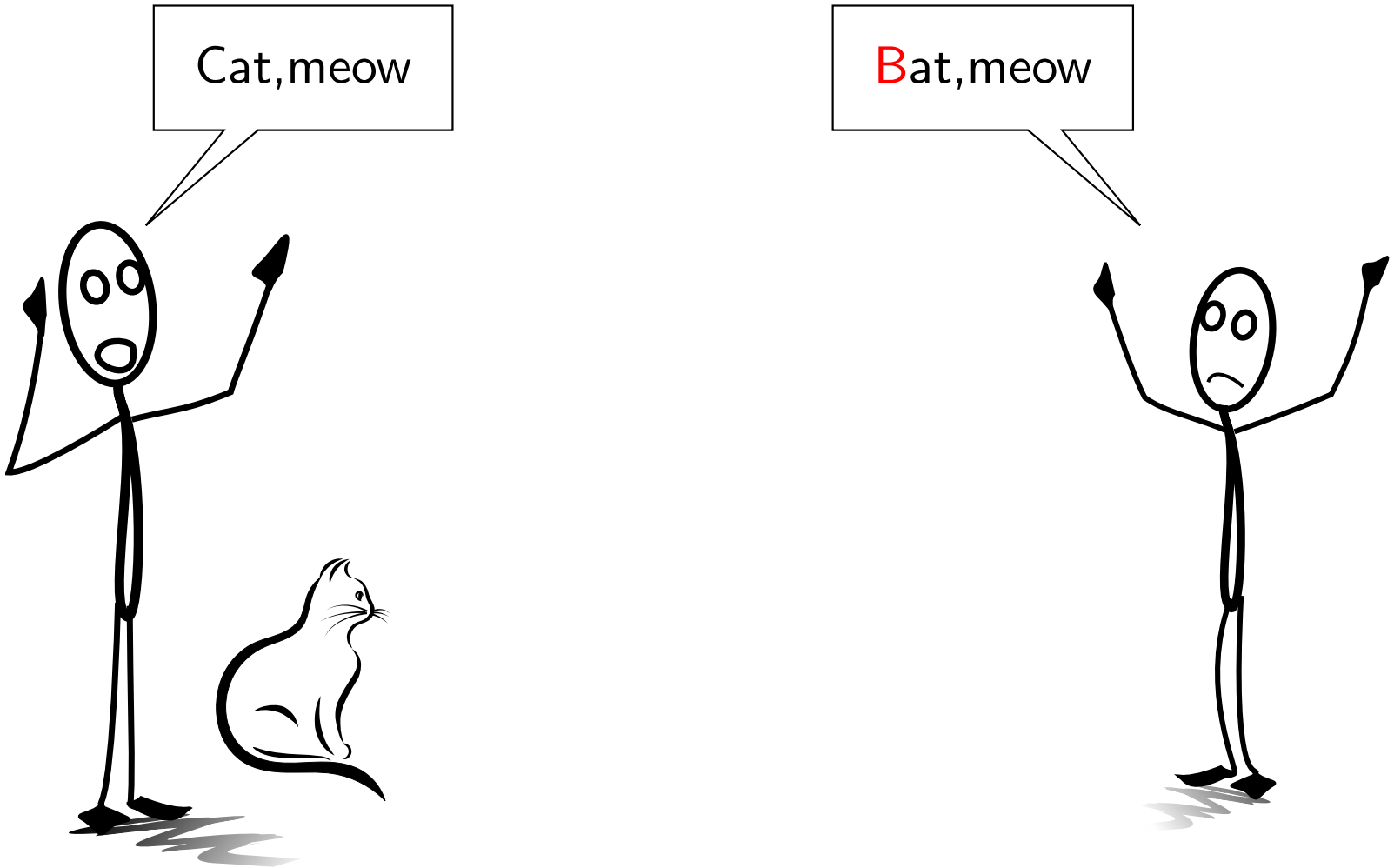

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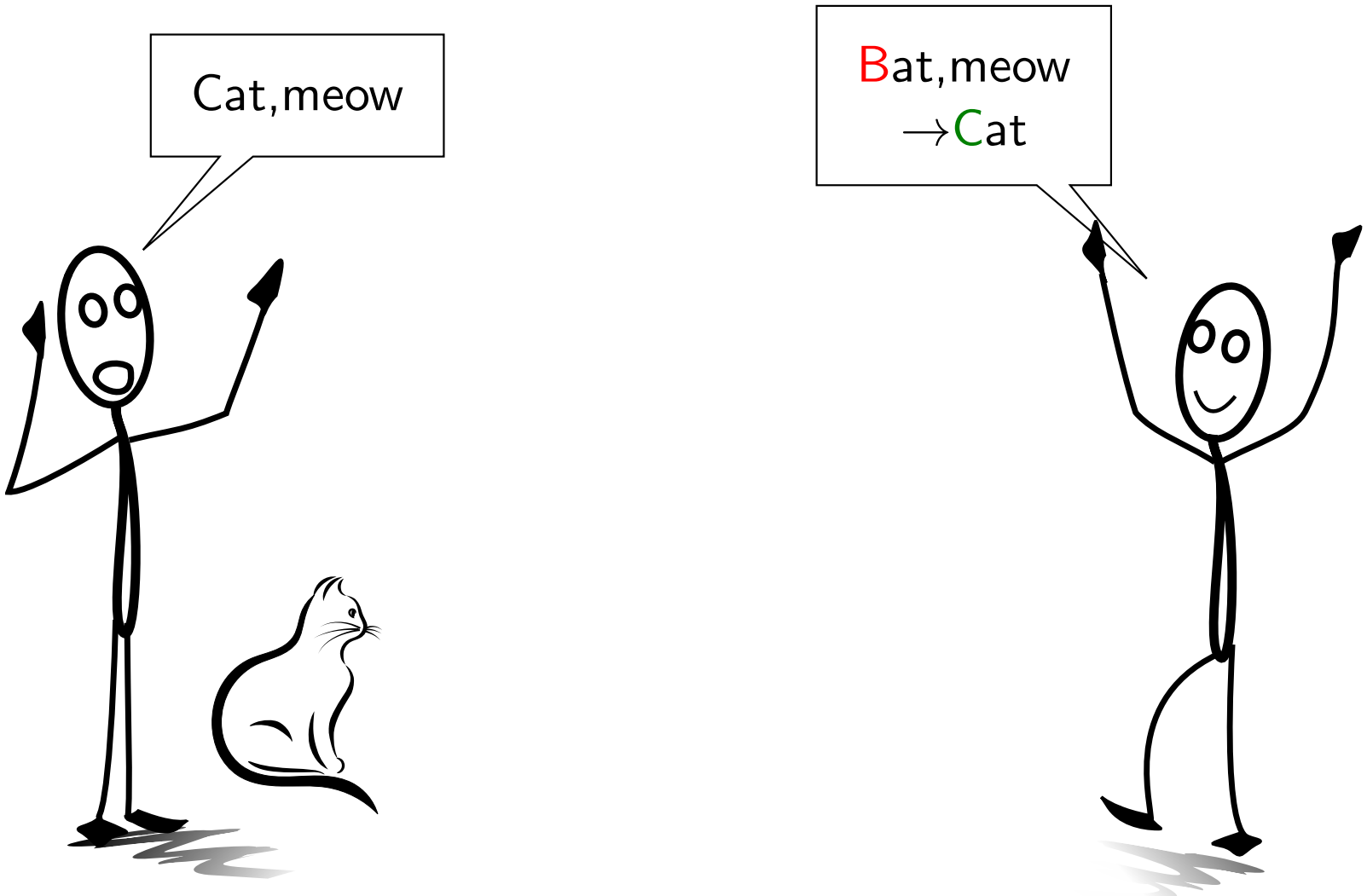

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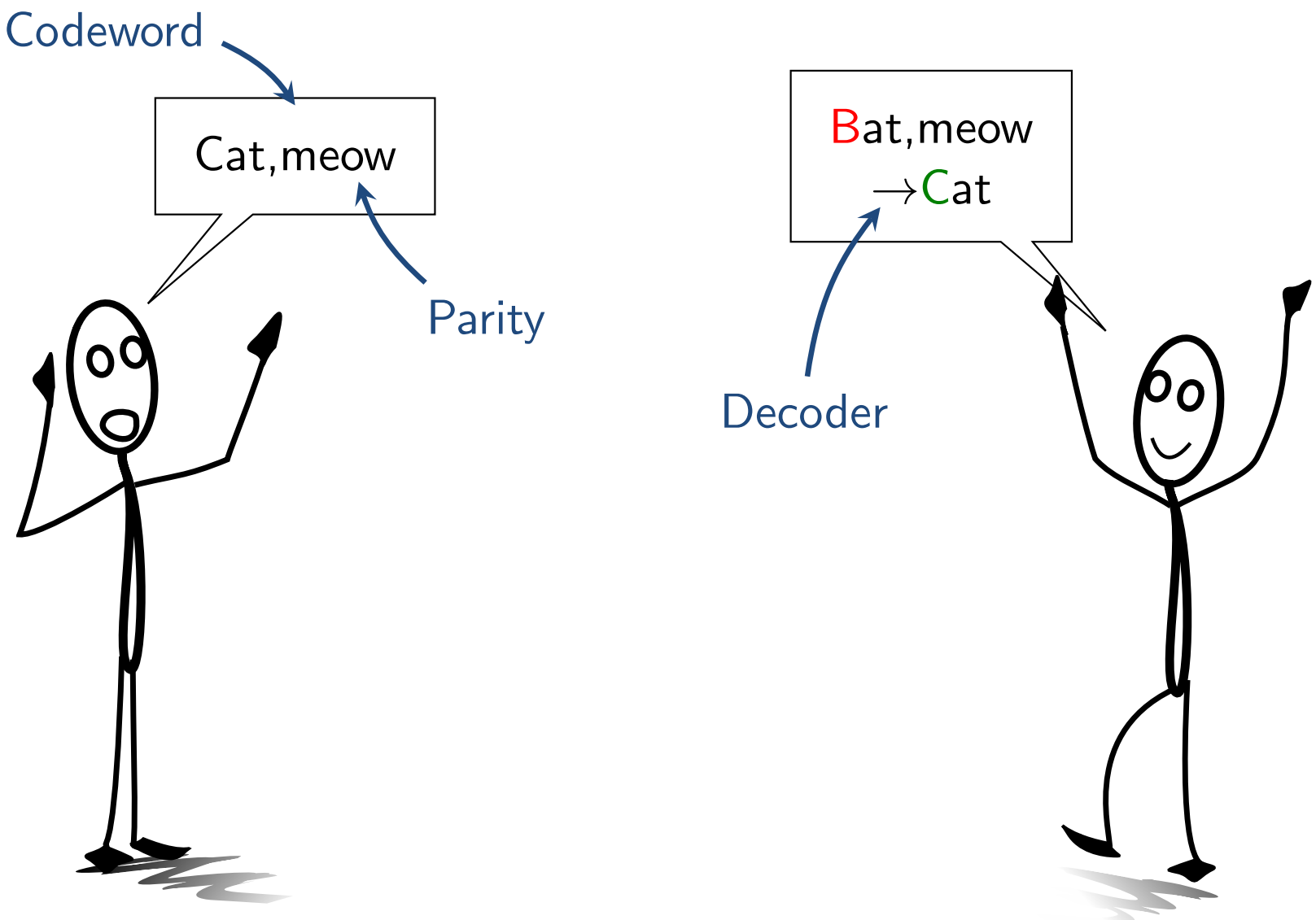

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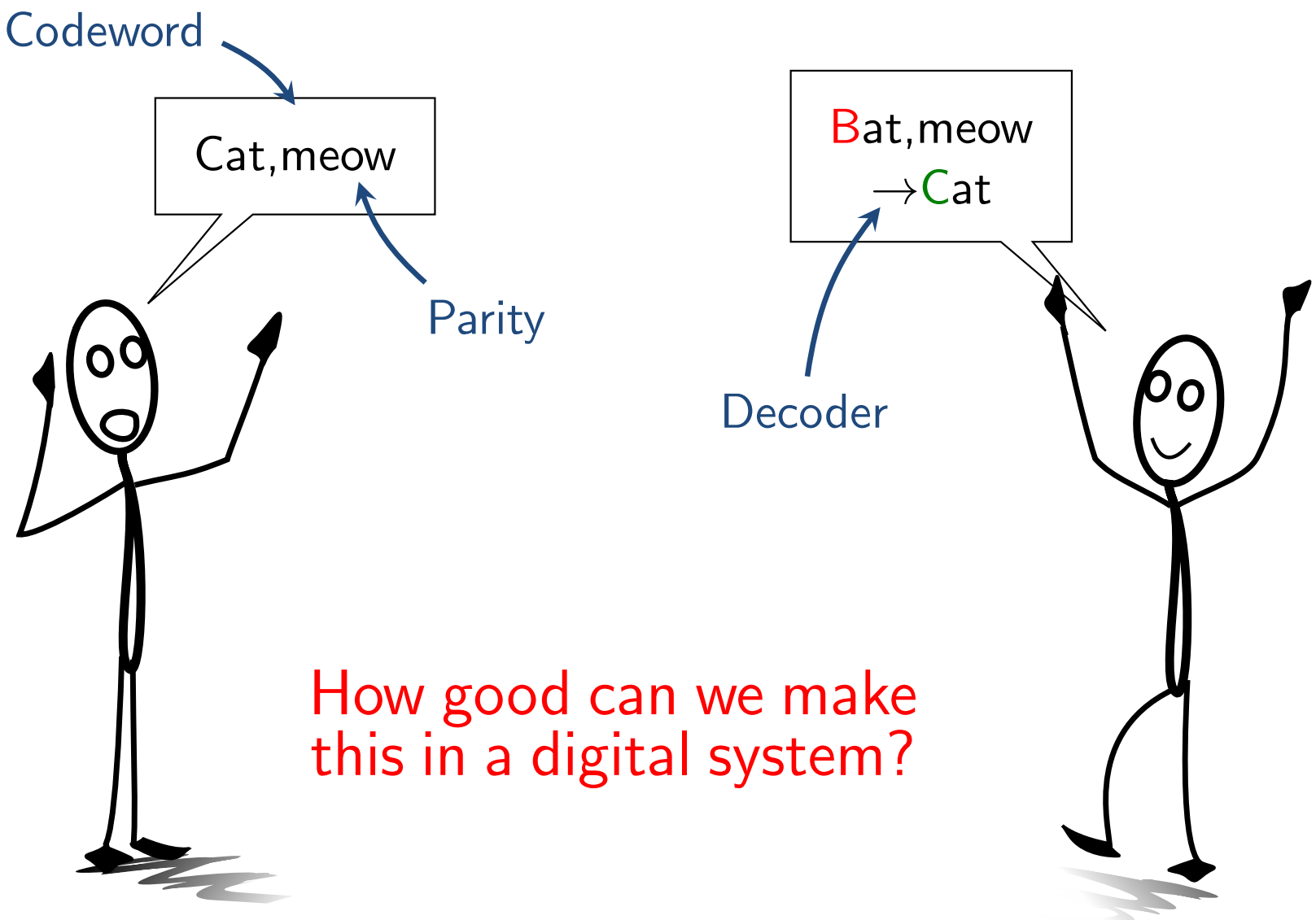
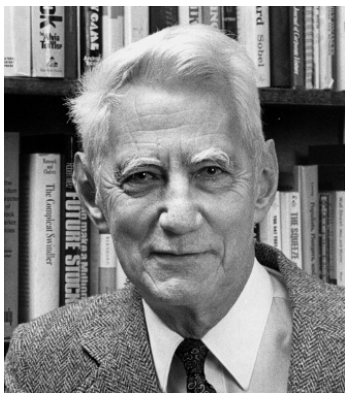


How good can we make this in a digital system?

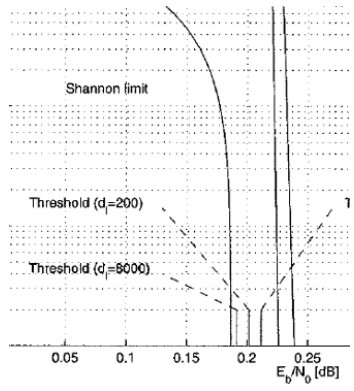
Achieving the Channel Capacity



Definition
1948

LDPC Codes
1960

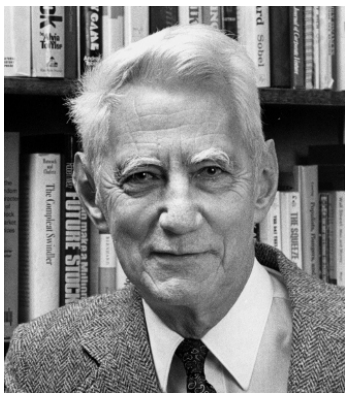
Turbo Codes
1993
0.7 dB



LDPC Codes
2004
0.04 dB

Polar Codes
2008
0 dB
using SC
as $N \to \infty$

Achieving the Channel Capacity



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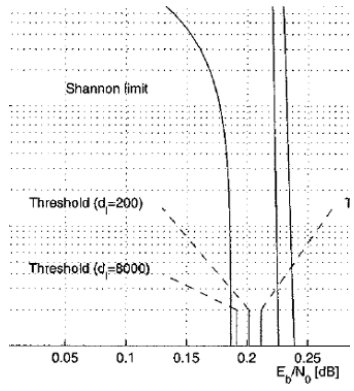


LDPC Codes
2004
0.04 dB

Polar Codes
2008
0 dB
using SC
as $N \to \infty$

Very challenging in software.

Achieving the Channel Capacity

Successive cancellation $\rightarrow$ low throughput.

$\Rightarrow$ Use a better algorithm.

Polar Codes

2008

0 dB

using SC

as $N \rightarrow \infty$

Performance at moderate code-length is modest.
Becomes excellent with $N > 2^{20}$.

$\Rightarrow$ Still competitive under some conditions;
use long frames if required.

Fast-SSC Decoding

What better algorithm? Fast-SSC!

- Orders of magnitude more efficient than SC;
- Maps nicely into SIMD;
- Memory can be arranged in an efficient way;
- Natural fit for systematic coding.

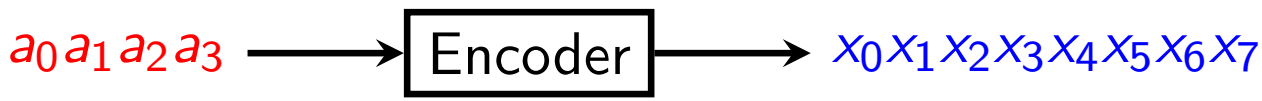
Wait! What is a systematic code?

Sarkis, Giard, Vardy, Thibeault and Gross, "Fast Polar Decoders: Algorithm and Implementation," IEEE JSAC, 2014.

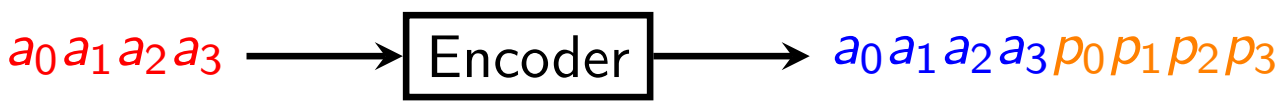
Non-systematic and Systematic Coding

(8, 4) code $\rightarrow$ 8-bit codeword: 4 information bits + 4 parity bits.

- Non-systematic:



- Systematic:



Non-systematic Polar Encoding

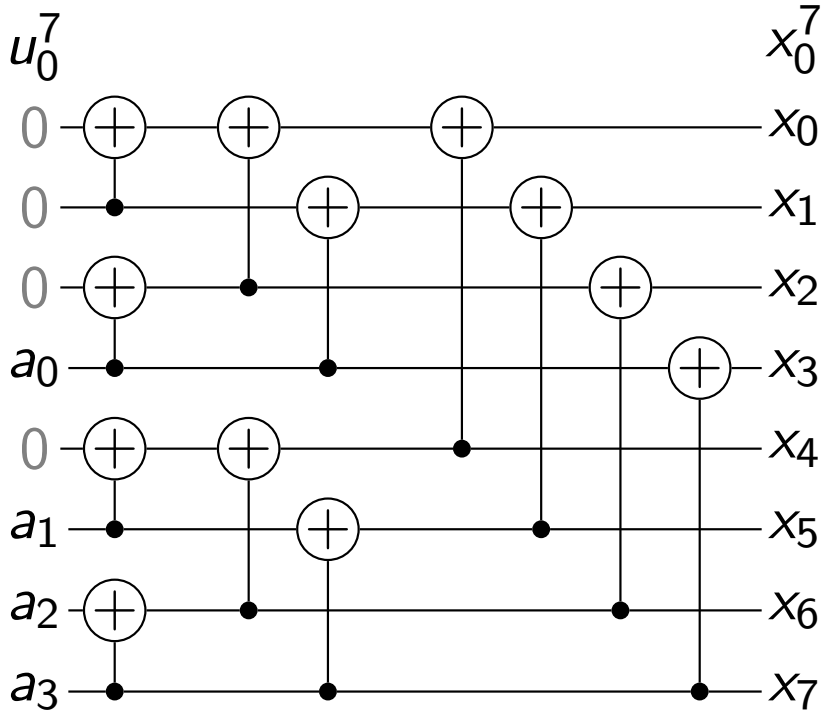


Figure : Structure for a $(8, 4)$ polar code.

Systematic Polar Encoding

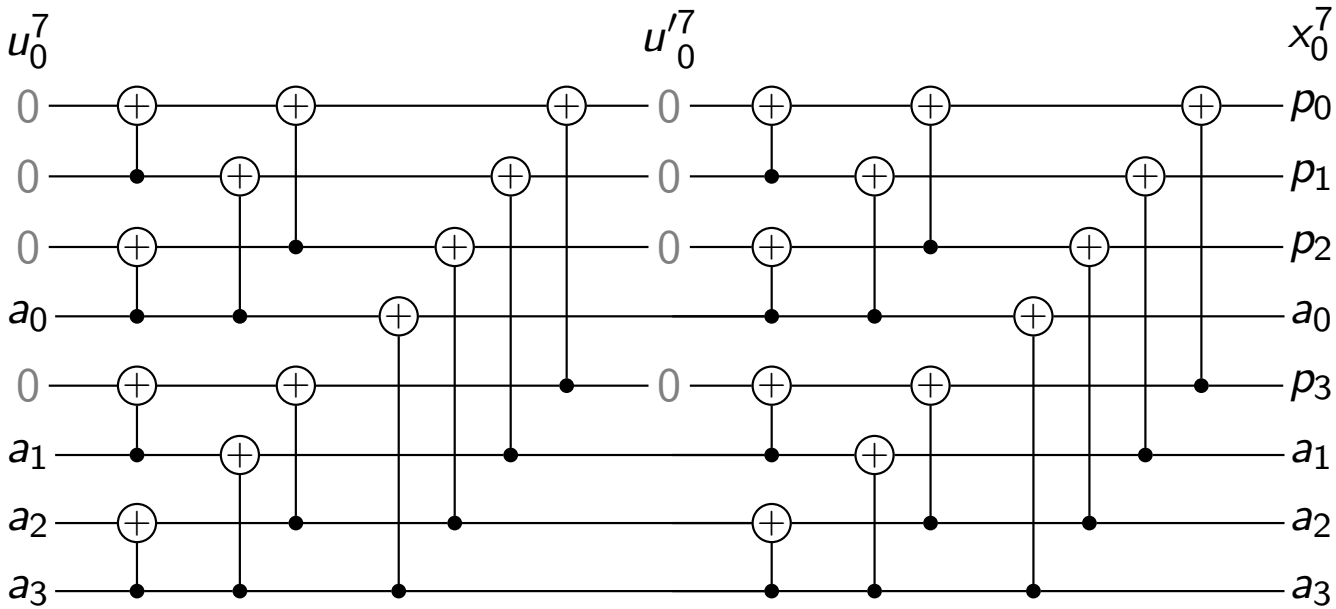


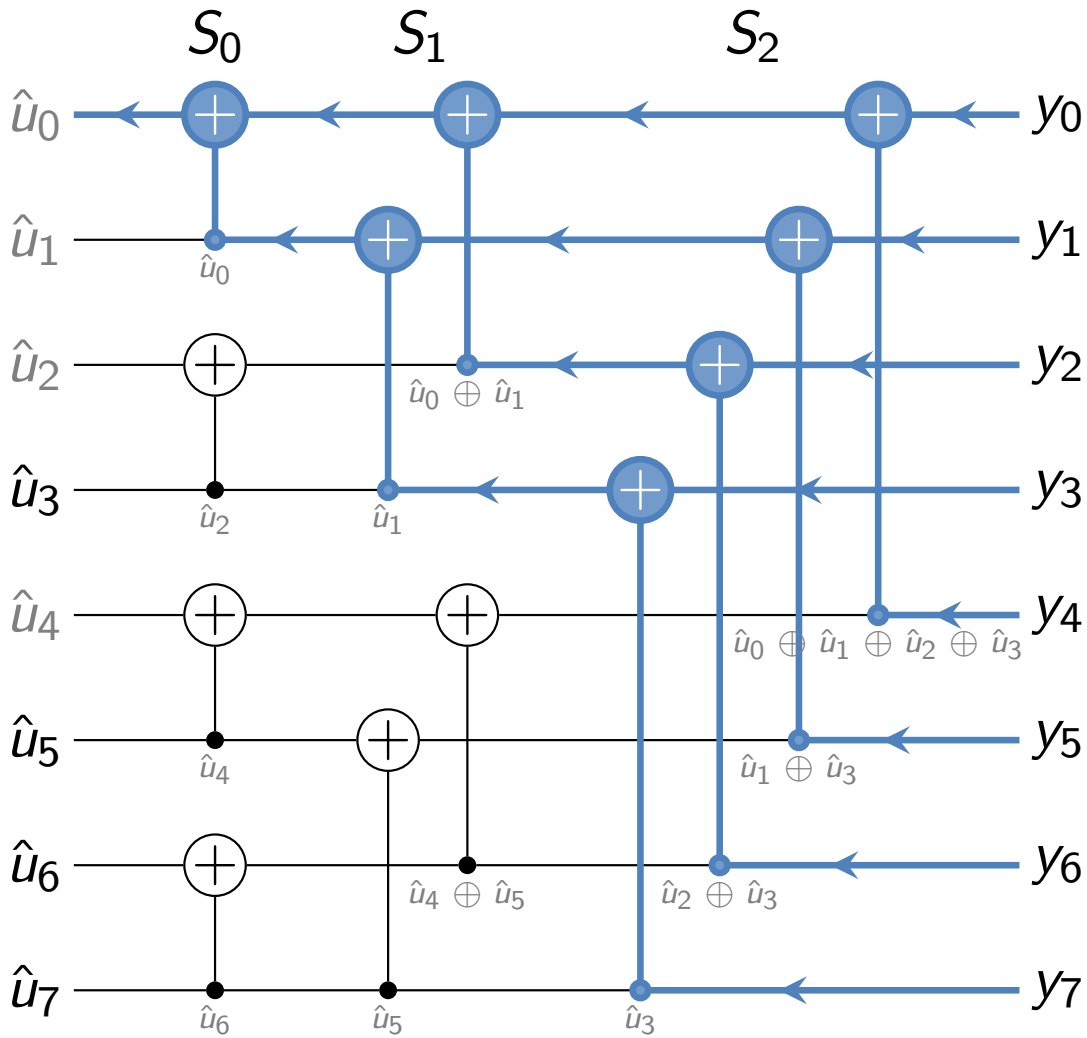
Figure : Low-complexity structure for a $(8, 4)$ polar code.

Alright, now how do we go from SC to Fast-SSC decoding?

Sarkis, Giard, Vardy, Thibeault and Gross, "Fast Polar Decoders: Algorithm and Implementation," IEEE JSAC, 2014.
Sarkis, Tal, Giard, Vardy, Thibeault and Gross "Flexible and Low-Complexity Encoding and Decoding of Systematic Polar Codes," *submitted to* IEEE TCOM and ArXiv, 2015.

Successive-Cancellation Decoding

- Reminder of how SC decoding works.



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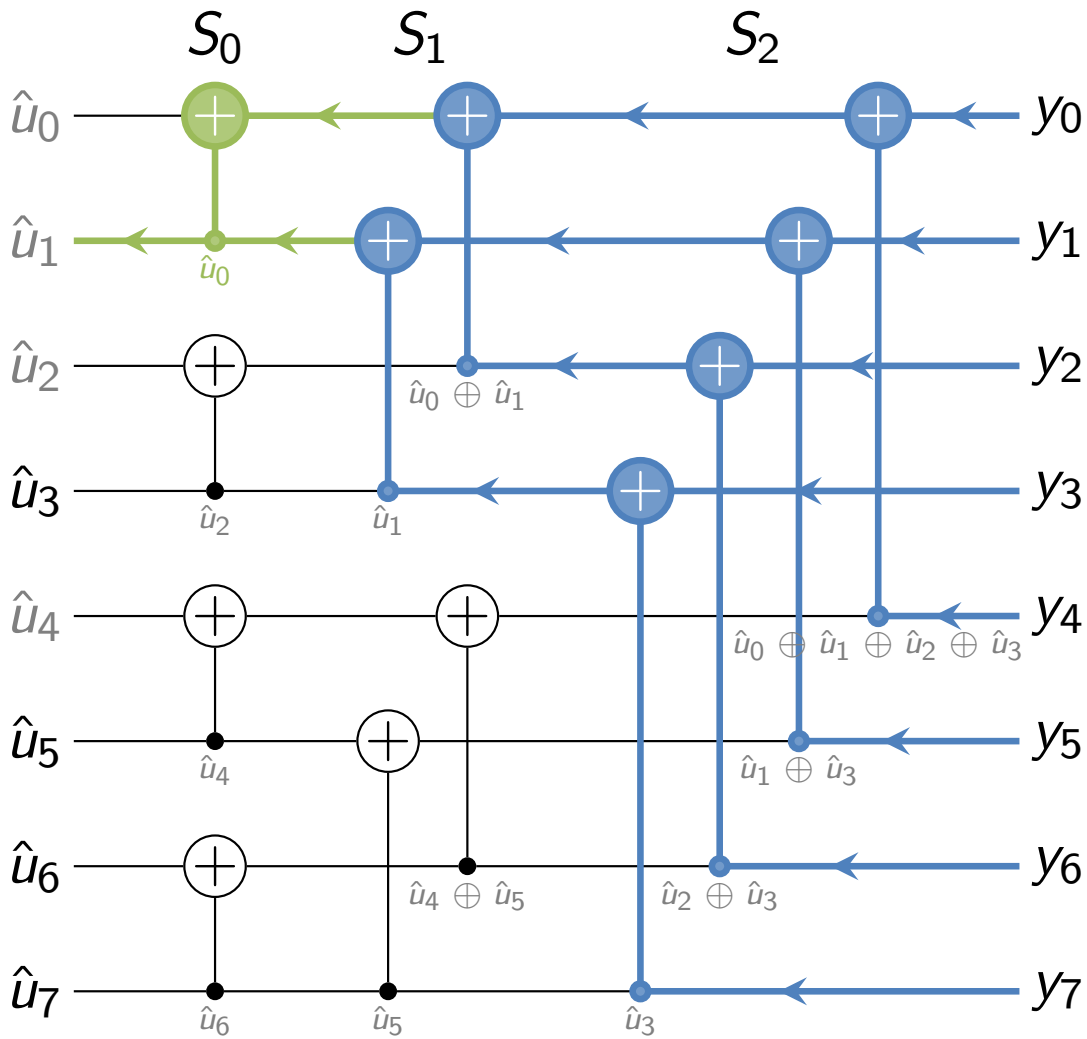
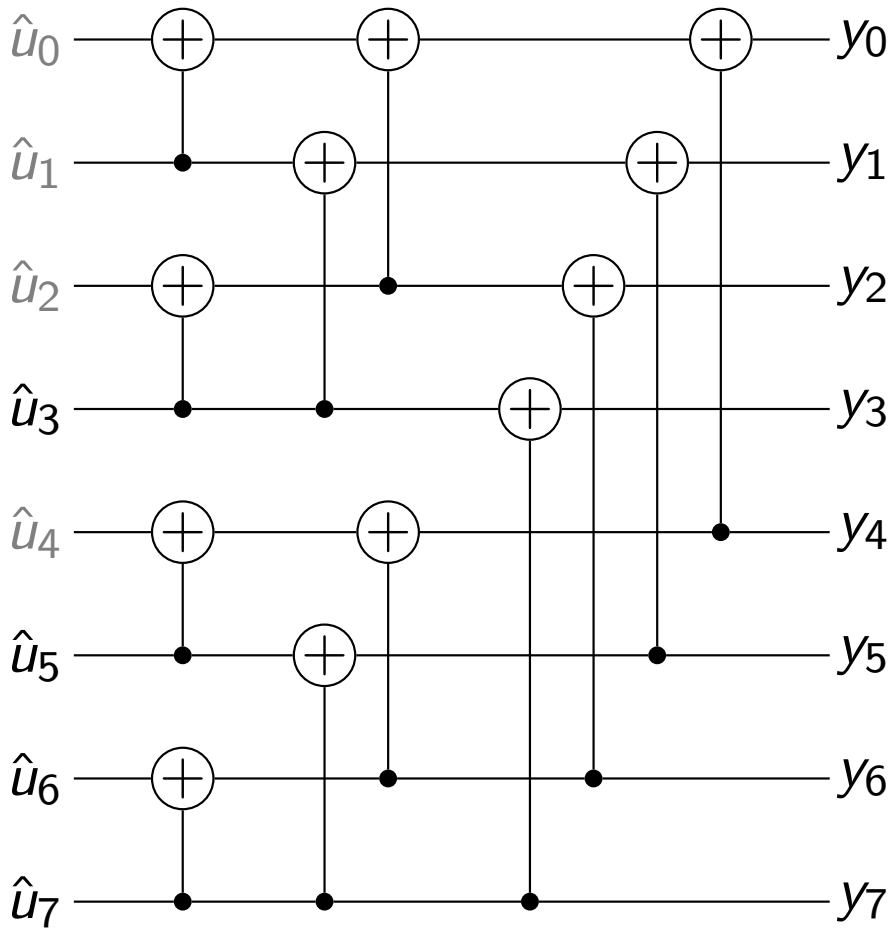


Successive-Cancellation Tree

- View the SC decoder graph as a tree.



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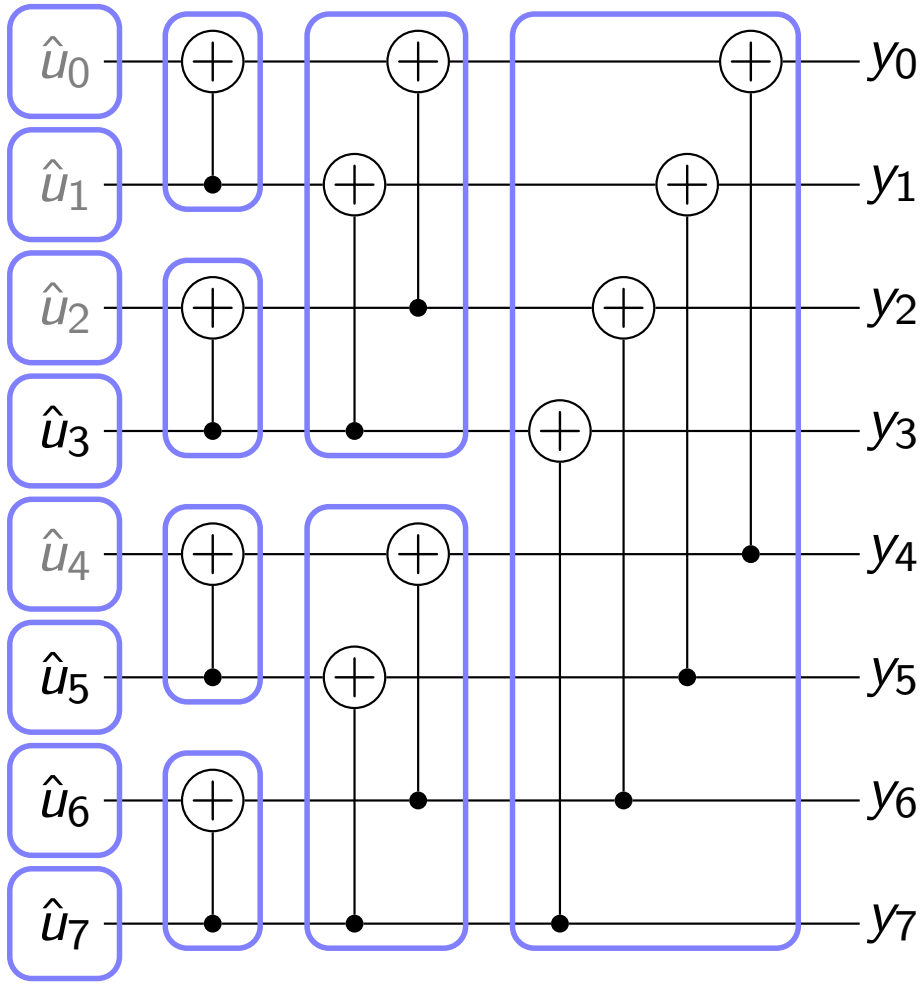

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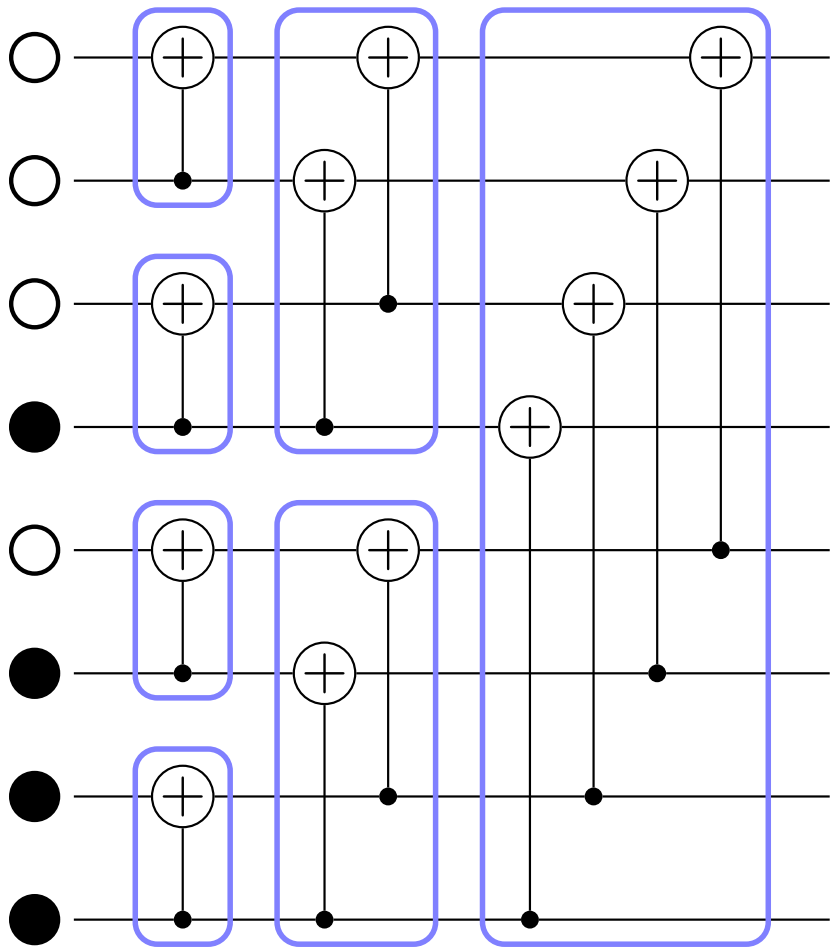
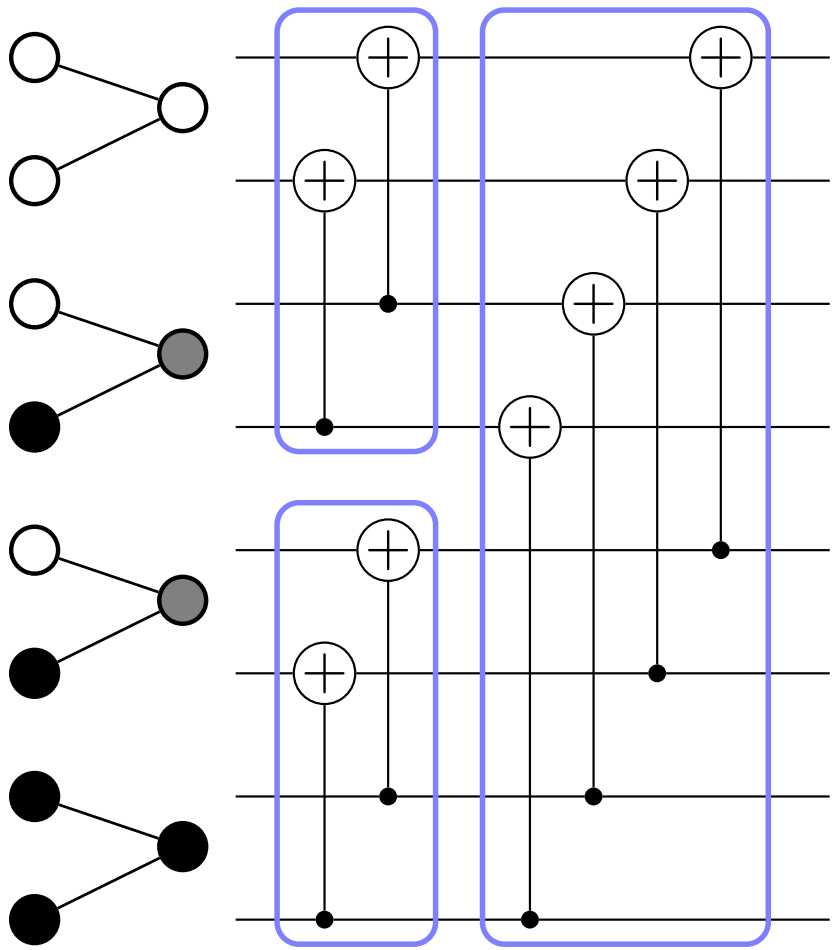


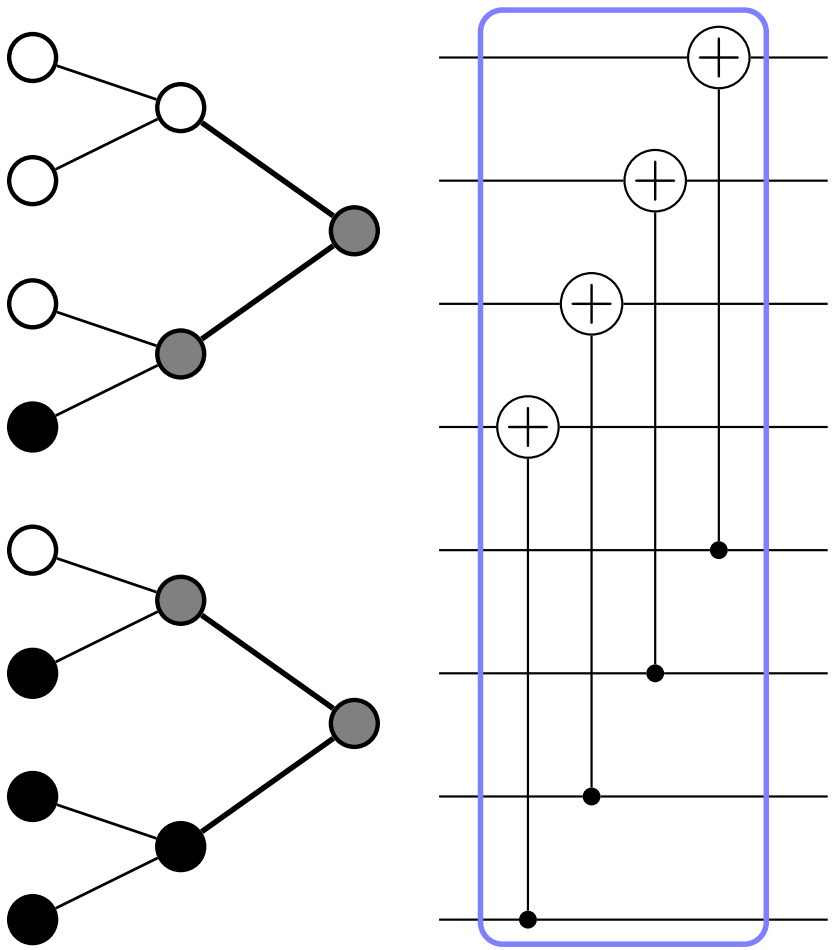
Successive-Cancellation Tree

- View the SC decoder graph as a tree.



Successive-Cancellation Tree

- View the SC decoder graph as a tree.



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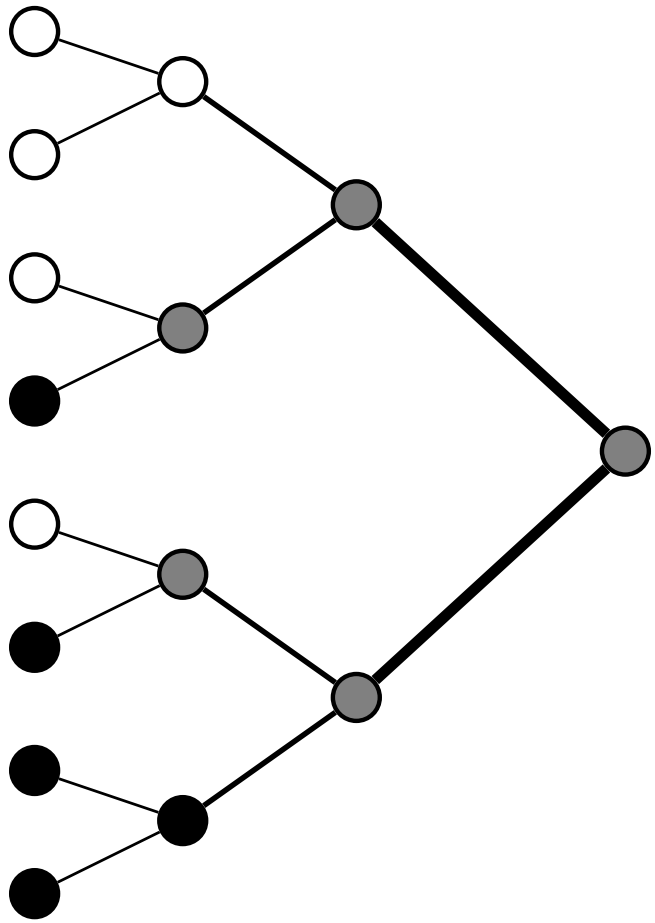
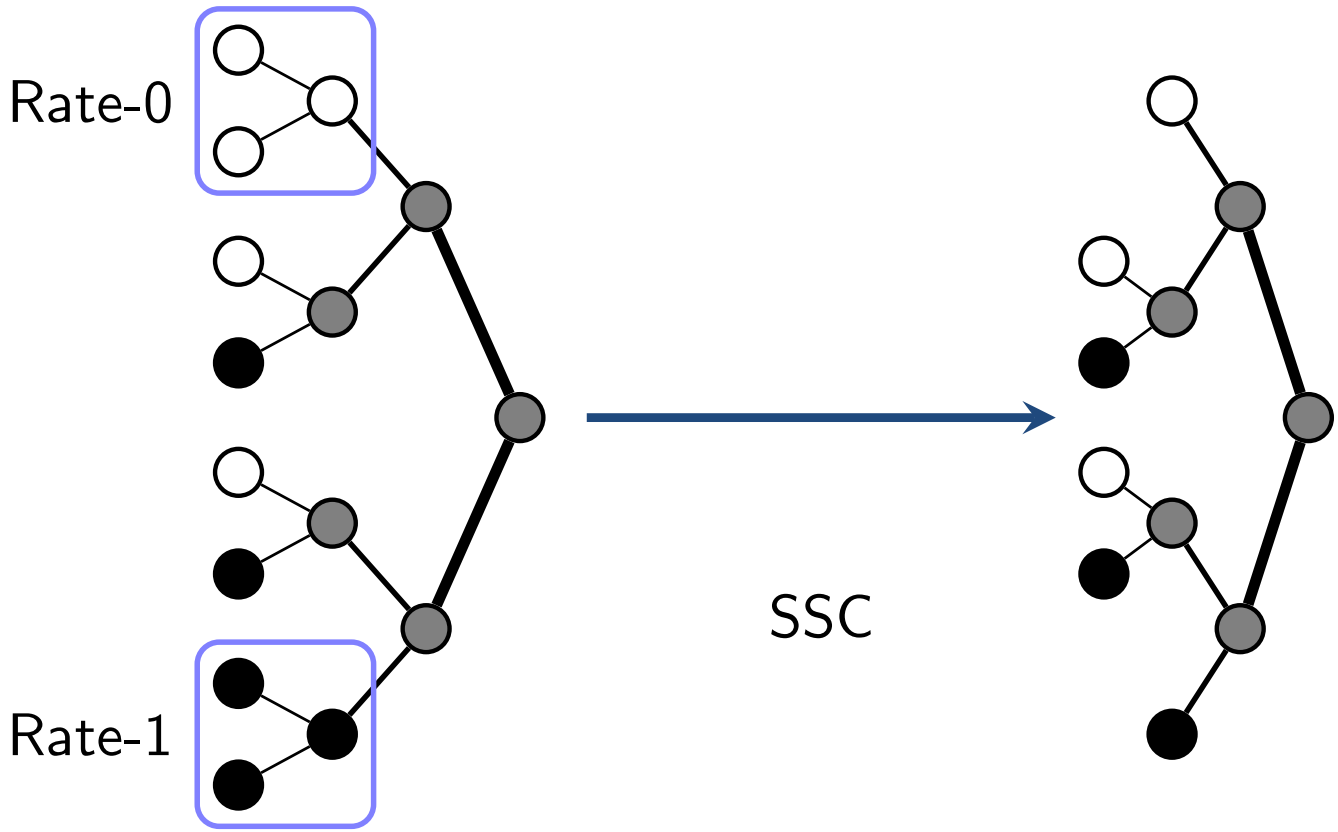
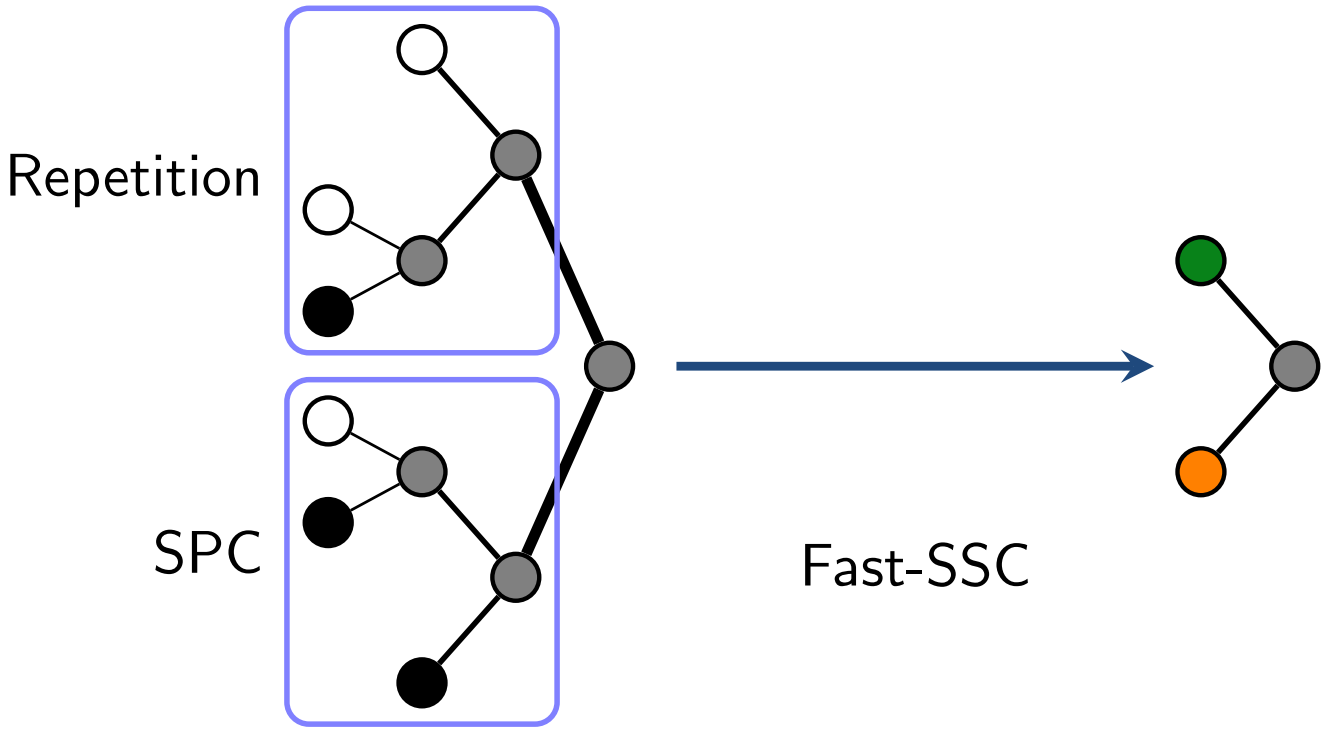


Simplified Successive Cancellation



Alamdar-Yazdi and Kschischang., "A Simplified Successive-Cancellation Decoder for Polar Codes," Comm. Lett., 2011.

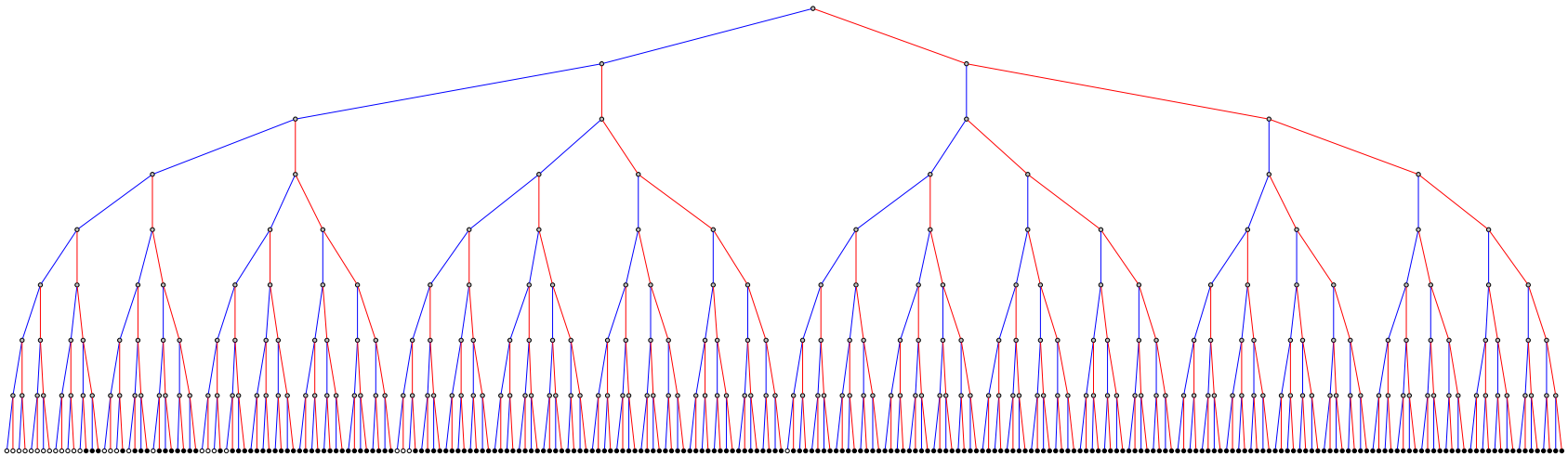
Fast-SSC Decoding



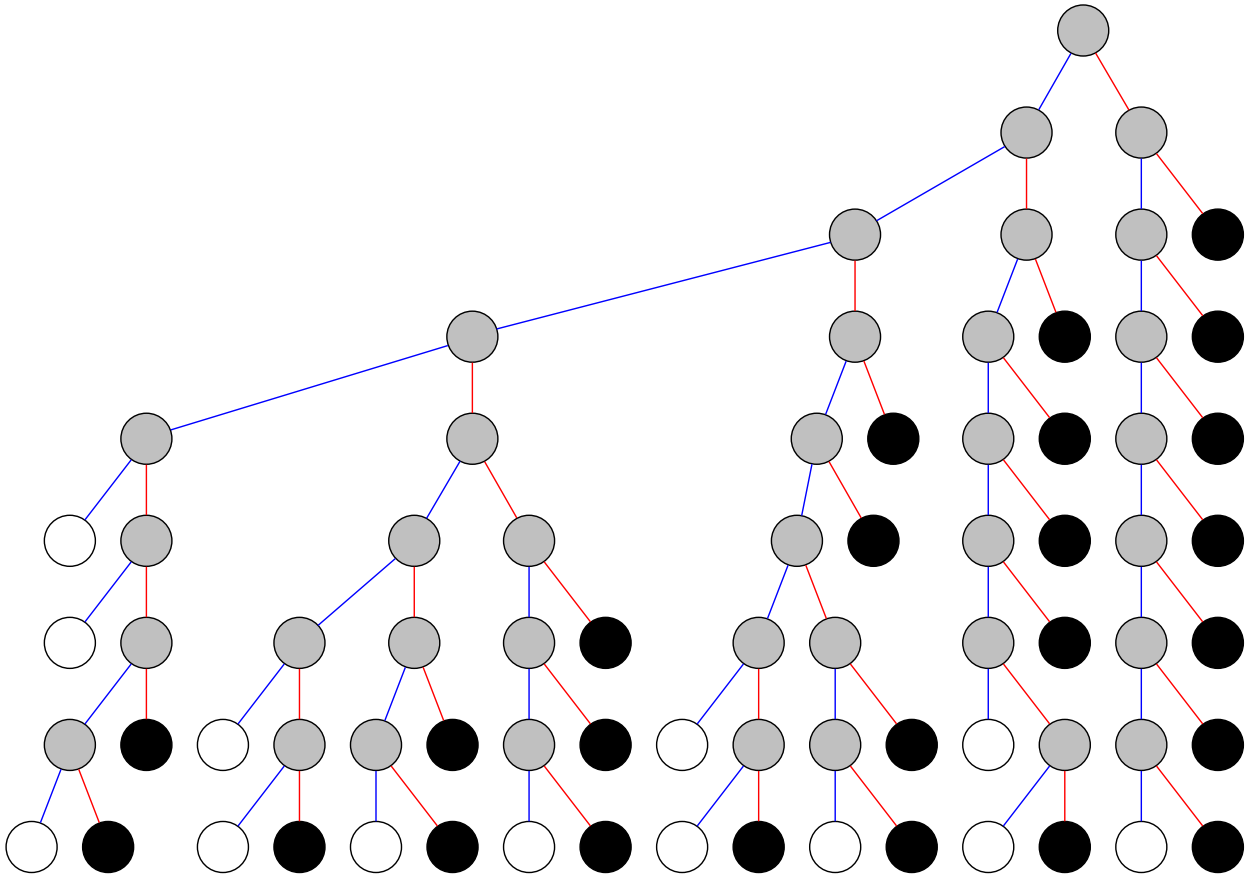
- Key idea: use more efficient algorithms on constituent codes.
- Fast-SSC supports more node types not covered here.

Sarkis, Giard, Vardy, Thibeault and Gross, "Fast Polar Decoders: Algorithm and Implementation," IEEE JSAC, 2014.

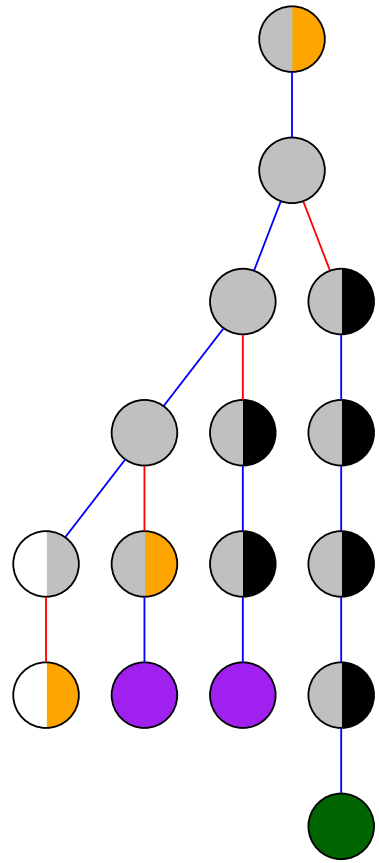
SC Tree—(256, 230)



SSC and Fast-SSC Trees—(256, 230)



SSC

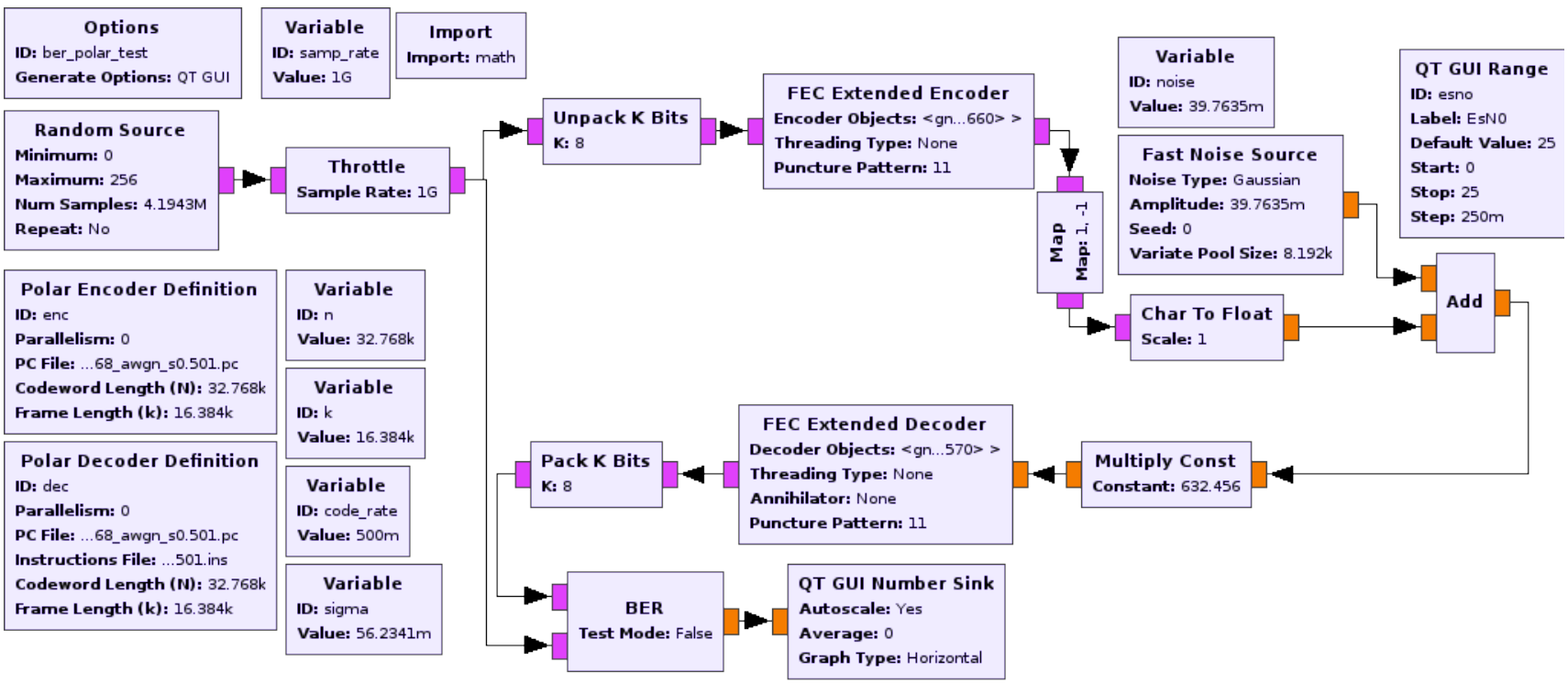


Fast-SSC

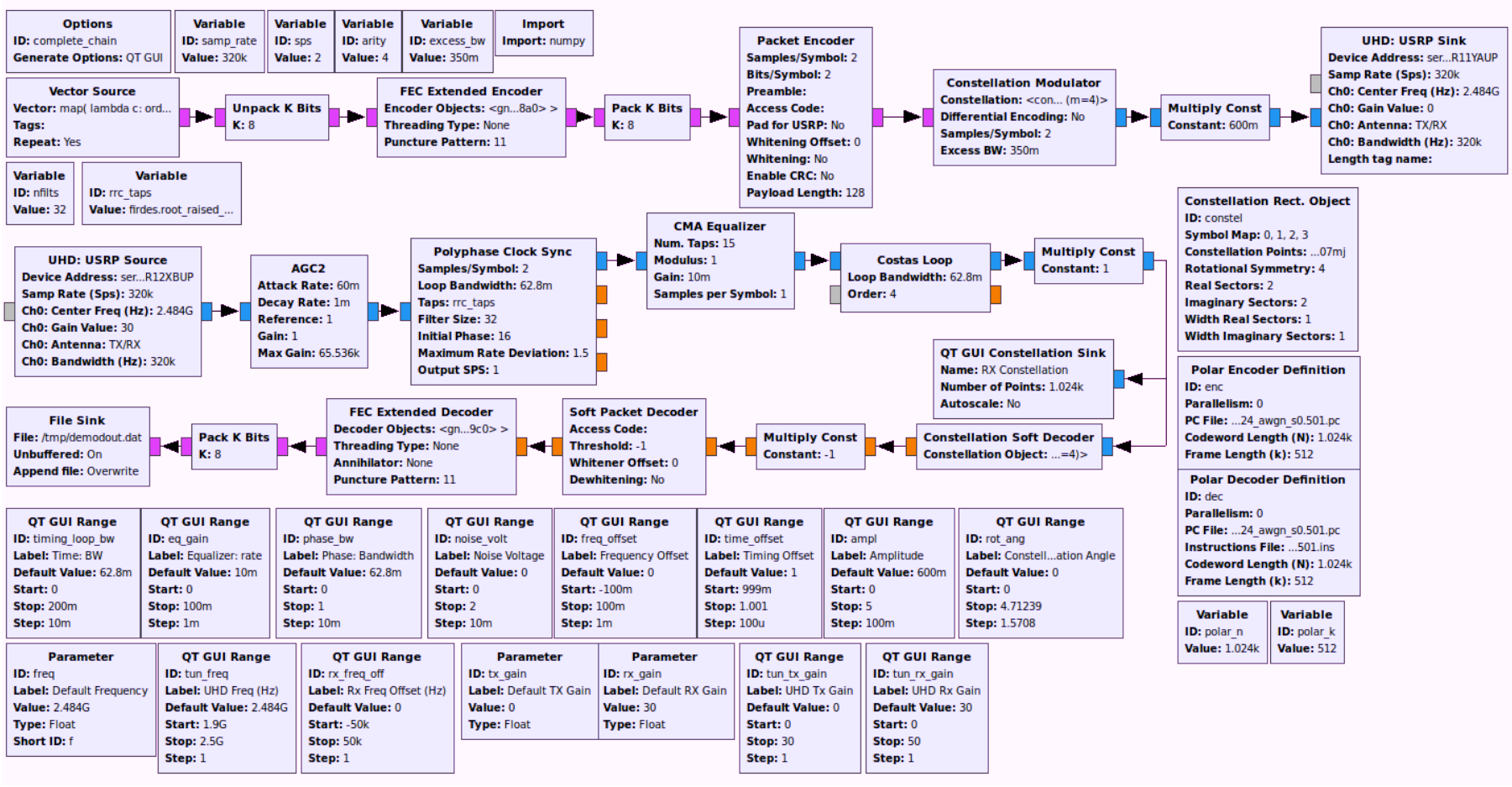
Implemention for GNU Radio

- Systematic polar coding for better BER.
- Supports a subset of the Fast-SSC nodes.
- Uses the FEC API.
- Supports soft inputs for greater error-correction performance.
- Uses fixed-point arithmetic internally.
- Highly-optimized VOLK kernels for SSE4, AVX2 and NEON.

Classical GRC Example



Complete Chain Example



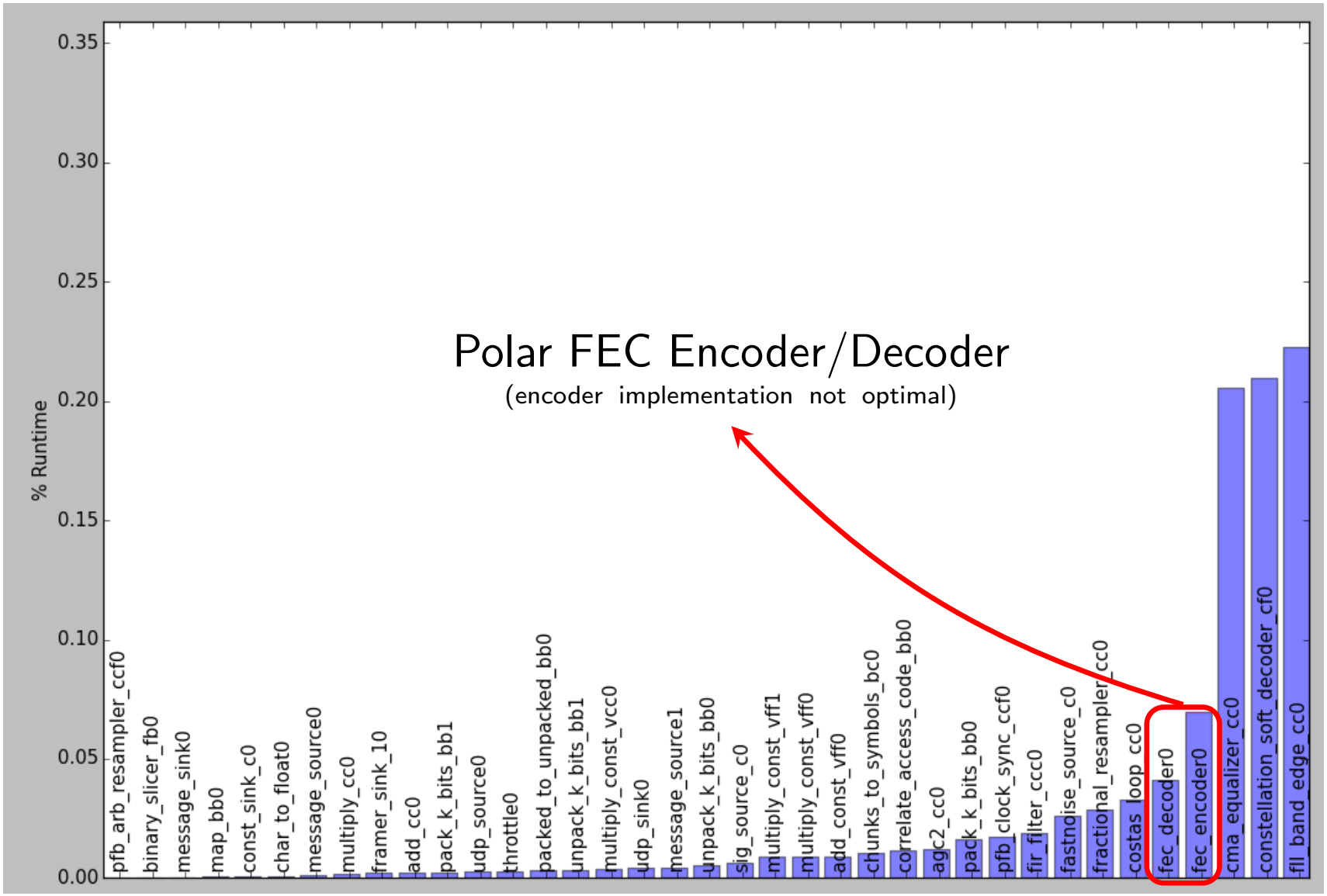
Performance Results

Using a single processor core:

- Under the worst conditions, a stable 50 Mbps on a low-power SandyBridge with SSE4.1.
- Under good conditions, an average coded throughput of 350 Mbps on a Haswell with AVX2 is typical.

$\Rightarrow$ In a complete communication chain, the modern FEC is NOT the bottleneck anymore.

Performance Results Example



Final Words

- Will this be upstreamed to GNU Radio/VOLK?
- Will we make the source code available?
- When can you start using it?
- What if you want to use polar codes outside GNU Radio?

Acknowledgement

The authors would like to warmly thank:

- Profs. Ghyslain Gagnon and Claude Thibeault of ETS for funding this trip.
- Prof. François Gagnon of ETS for HW access and helpful discussions.
- Gabi Sarkis of McGill university for helpful discussions and presentation material.

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