High-SNR Asymptotics of Entropy-Constrained Gaussian Channel Capacity

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joint work with Shlomo Shamai and Emre Telatar

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Entropy-constrained capacity

$$\max_{X} \; I(X; \sqrt{\mathsf{snr}}X + Z)$$

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$$C_H(h, \mathsf{snr}) = \max_X \; I(X; \sqrt{\mathsf{snr}}X + Z)$$

over X satisfying $\mathbb{E}[X^2] \leq 1$ and $H(X) \leq h$

Entropy-constrained capacity: High-SNR asymptotics

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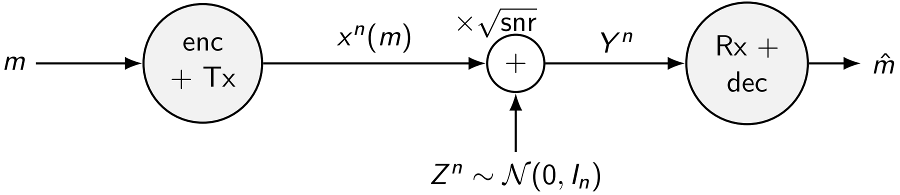
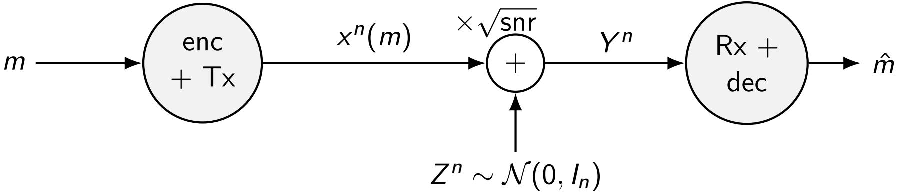
in particular: $h - C_H(h, \mathsf{snr})$ as $\mathsf{snr} \to \infty$

Gaussian channel



$$\frac{1}{M}\sum_{m=1}^{M}\frac{1}{n}\sum_{i=1}^{n}x_i^2(m)\le 1$$



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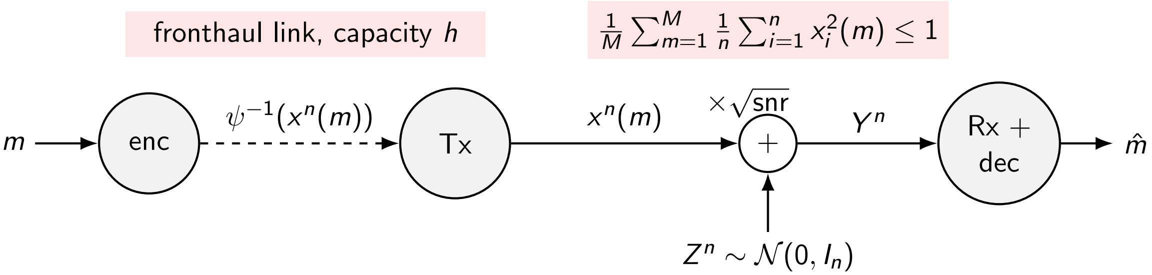

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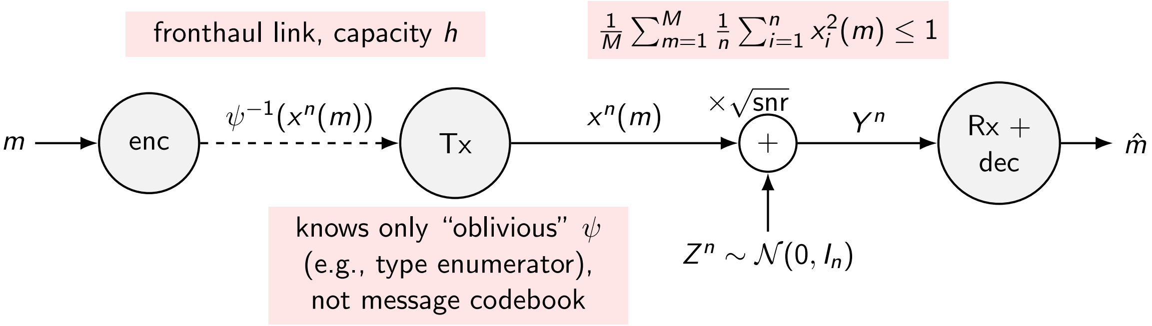

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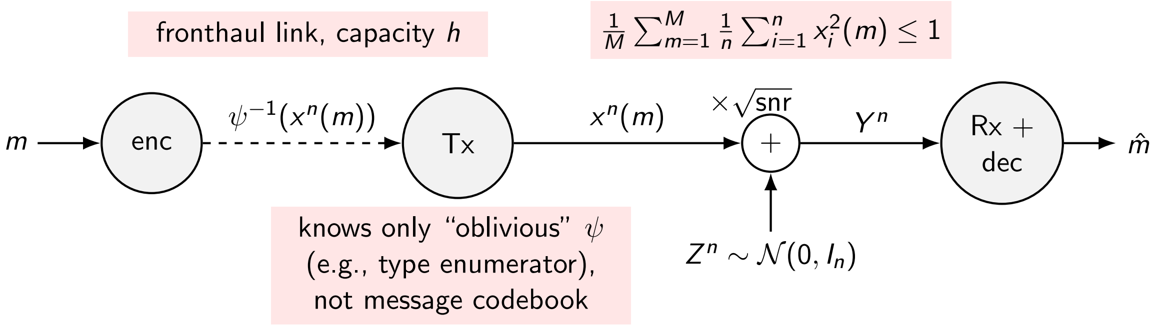

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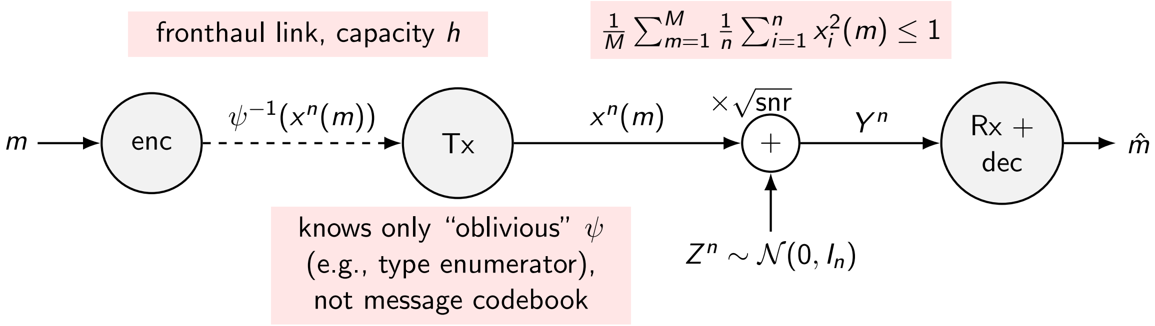

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- $\mathsf{snr} \to \infty$: $C_H(h, \mathsf{snr}) \to h$, so gap of interest $= h - C_H(h, \mathsf{snr}) = H(X^*_{h,\mathsf{snr}}) - I(X^*_{h,\mathsf{snr}}, \mathsf{snr})$

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Lemma

For any X with $\mathbb{E}[X^2] = 1$ and finite $H(X)$, and $Z \sim \mathcal{N}(0,1)$ independent of X, we have

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- and $C_H(h, \mathsf{snr}) = h - \mathrm{O}\big(\exp(-\mathsf{snr}\,\mathrm{d}_h^2/8)\big)$

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Proposition

Solution to $\mathsf{d}_h = \max \mathsf{d}_{\min}(X)$ *over all* X *with* $\mathbb{E}[X^2] = 1$ *and* $H(X) = h$ *is*

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- proof sketch: maximum at equally spaced distribution, then Lagrange dual

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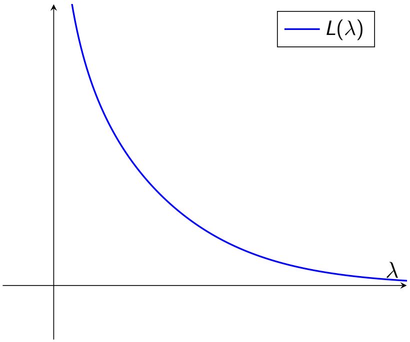

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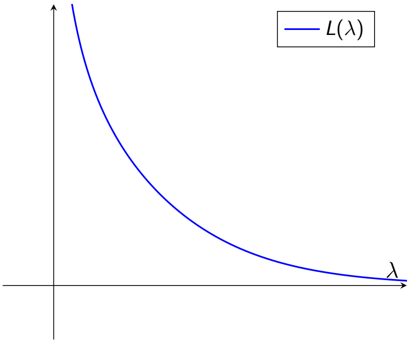

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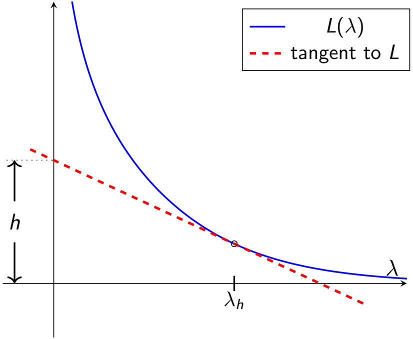

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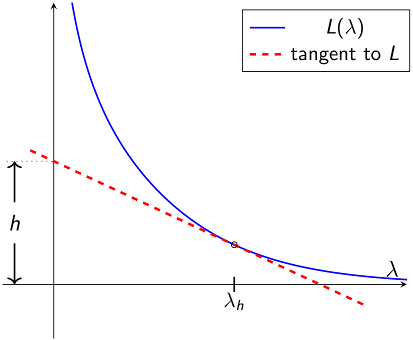

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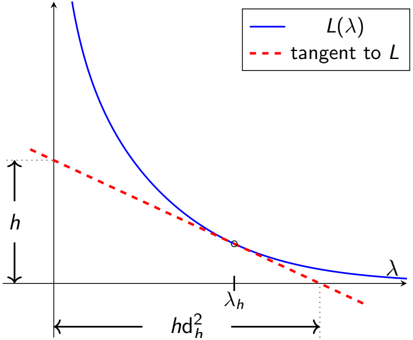

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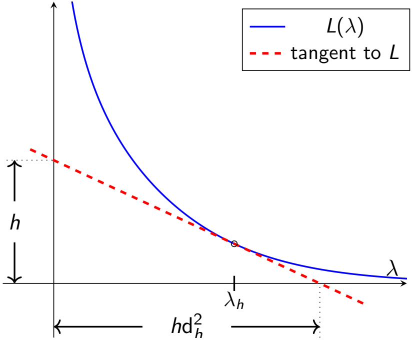

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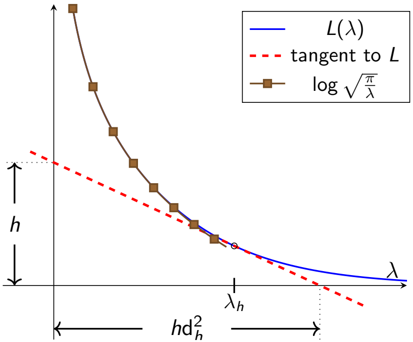

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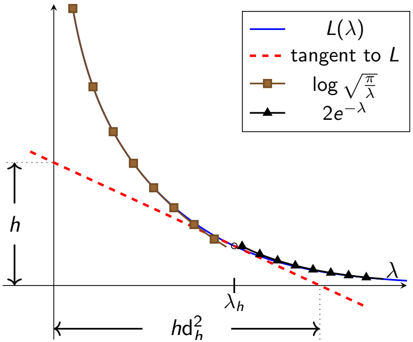
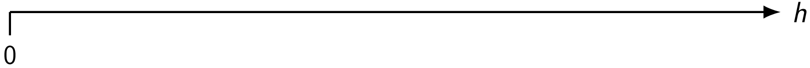


- approximations: $L(\lambda) \approx \log\sqrt{\frac{\pi}{\lambda}}$ for $\lambda \ll \pi$, $\quad L(\lambda) \approx 2e^{-\lambda}$ for $\lambda \gg \pi$

Low- and high-entropy approximations



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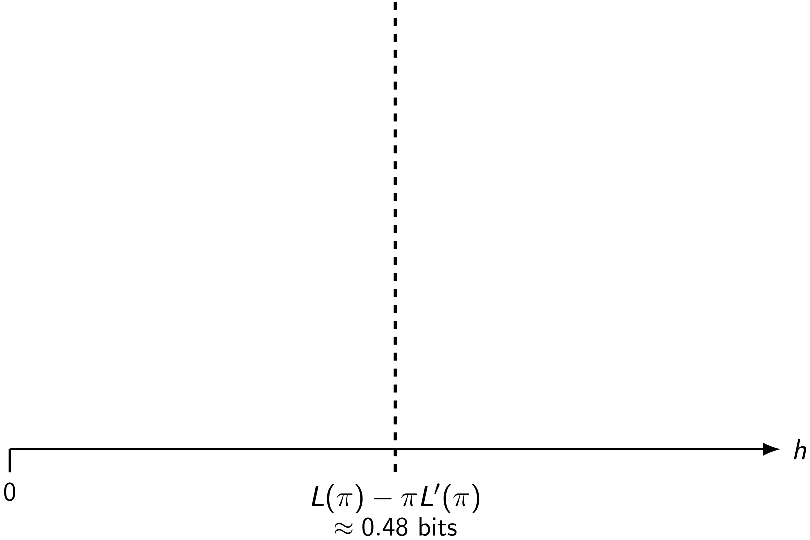

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$\mathrm{d}_h \approx$ $\sqrt{\frac{1}{h} \log \frac{2}{h}}$ $\sqrt{2\pi e}\exp(-h)$

h

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$L(\pi) - \pi L'(\pi)$
≈ 0.48 bits

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$\mathrm{d}_h \approx$	$\sqrt{\frac{1}{h}\log\frac{2}{h}}$	$\sqrt{2\pi e}\exp(-h)$
$h - C_H(h, \mathrm{snr}) \approx$	$\mathrm{O}\Big(\exp\big(-\mathrm{snr}\frac{\log\frac{2}{h}}{8h}\big)\Big)$	$\mathrm{O}\Big(\exp\big(-\mathrm{snr}\frac{\pi e}{4}\, e^{-2h}\big)\Big)$

h

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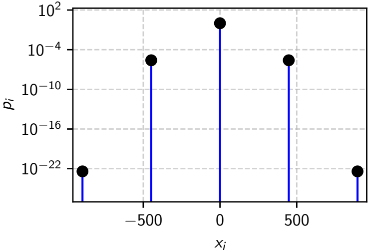
$$h - C_H(h, \mathrm{snr}) \approx \mathrm{O}\Big(\exp\big(-\mathrm{snr}\frac{\log\frac{2}{h}}{8h}\big)\Big) \qquad \Big| \qquad \mathrm{O}\Big(\exp\big(-\mathrm{snr}\frac{\pi e}{4}e^{-2h}\big)\Big)$$

$X_h \sim$



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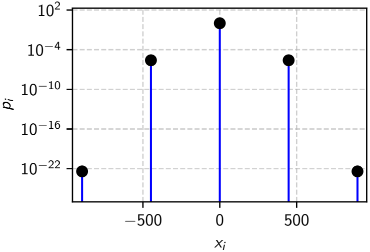
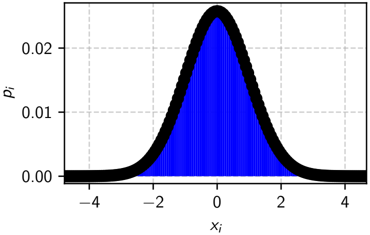
Low- and high-entropy approximations

$$\mathrm{d}_h \approx \quad \sqrt{\frac{1}{h}\log\frac{2}{h}} \qquad \Big| \qquad \sqrt{2\pi e}\exp(-h)$$

$$h - C_H(h,\mathrm{snr}) \approx \quad \mathrm{O}\left(\exp\left(-\,\mathrm{snr}\frac{\log\frac{2}{h}}{8h}\right)\right) \qquad \Big| \qquad \mathrm{O}\left(\exp\left(-\,\mathrm{snr}\frac{\pi e}{4}\,e^{-2h}\right)\right)$$

$X_h \sim$





$$\xrightarrow{h\to\infty} \mathcal{N}(0,1)$$

h

0

$L(\pi) - \pi L'(\pi)$

≈ 0.48 bits

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Thank you!