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ENGAGING THE WORLD

CONDITIONAL AND RESIDUAL METHODS IN SCALABLE CODING FOR HUMANS AND MACHINES

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GOAL

We would like to ***compose*** *the information required for tasks in a* ***scalable*** *fashion, in which base representations are* ***shared*** *among multiple tasks and only* ***incremental*** *amounts of information are required for more specific tasks.*

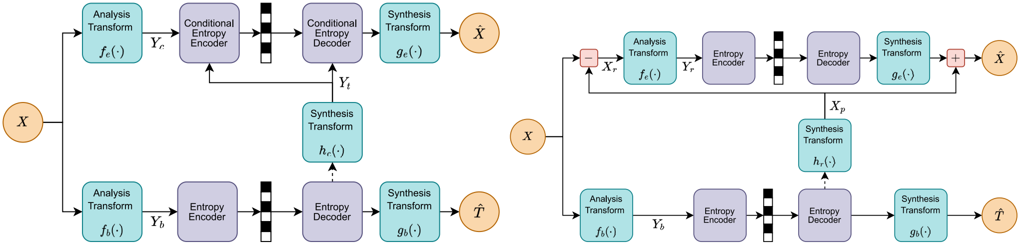
CONTRIBUTIONS

1. Conditional and residual approaches in *scalable image coding for humans and machines*[1]
2. Upper and lower baselines
3. Entropy model for conditional coding
4. Empirical results on semantic image segmentation and object detection

[1] H. Choi and I. V. Bajić. "Scalable Image Coding for Humans and Machines". In: *IEEE TIP* 31 (2022), pp. 2739–2754.

- Dedicated and shared representations are concatenated and used as input for a target task
- Results show considerable redundancy[2]

[2] E. Ozyilkan et al. "Learned Disentangled Latent Representations for Scalable Image Coding for Humans and Machines". In: *arXiv 2301.04183* (2023); Choi and Bajić, "Scalable Image Coding for Humans and Machines".



(a) Conditional

(b) Residual

Figure 1: Overall architecture of the conditional and residual methods.

LOSSLESS BOUNDS FOR CONDITIONAL CODING

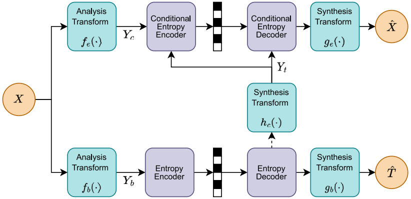
- We model $H(Y_b) + H(Y_c|Y_t)$
- Lower bound:

$$H(Y_c) \leq H(Y_b) + H(Y_c|Y_t). \qquad (1)$$

- Tight when $H(Y_b) = I(Y_c; Y_t)$
- Upper bound:

$$H(Y_b) + H(Y_c|Y_t) \leq H(Y_b) + H(Y_c). \qquad (2)$$

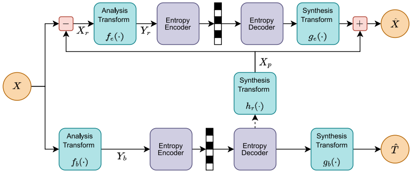
- Tight when $I(Y_c; Y_t) = 0$



Conditional coding is an upper bound of residual coding[3]:

$$H(X|X_p) \leq H(X_r) = H(X|X_p) + I(X_p; X_r). \quad (3)$$

$I(X_p; X_r)$ acts as a penalty term.

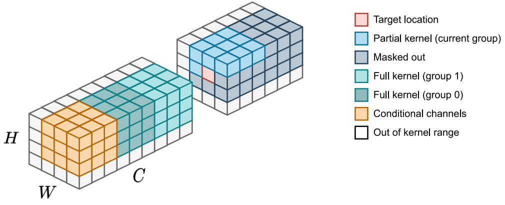


[3] F. Brand, J. Seiler, and A. Kaup. "On Benefits and Challenges of Conditional Interframe Video Coding in Light of Information Theory". In: *PCS*. 2022, pp. 289–293.

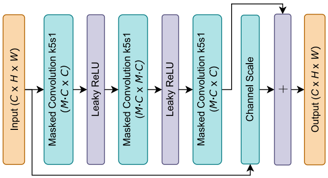
BASELINES FOR SCALABLE CONDITIONAL AND RESIDUAL CODING

- Rate-distortion bounds motivated by lossless bounds
- Upper baseline - Y_e generated without side information: $\hat{H}(Y_e) = R(D_{Y_e})$
- Lower baseline as $\hat{H}(Y_b) + \hat{H}(Y_e)$
- Identical baselines for both approaches since $H(Y_c|Y_t) = H(Y_r)$ is easier to achieve

ENTROPY MODEL FOR CONDITIONAL CODING



(a) Convolution mask

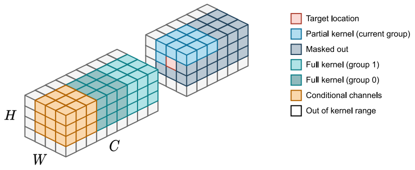


(b) CNN block

Figure 2: Entropy model overview.

ENTROPY MODEL FOR CONDITIONAL CODING

- Model spatial-dimensional dependencies using an auto-regressive CNN
- Scaled residual connections and kernels sizes larger than 1 throughout
- Group channels with fixed size K and process them in parallel
- All reachable locations in the previous groups as context [4]



[4] D. Minnen and S. Singh. "Channel-Wise Autoregressive Entropy Models for Learned Image Compression". In: *IEEE ICIP*. 2020, pp. 3339–3343.

- Small reconstruction penalty added to base layer RD objective:
  - Allows reconstruction task to use more available information

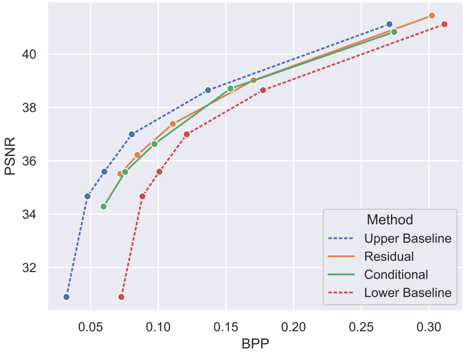
$$\mathcal{L}_b = D_b + \lambda_b \hat{H}(Y_b) + \beta\, \mathbb{E}[d_e(\hat{h}_r(Y_b), X)] \tag{4}$$

- Standard rate-distortion loss function for enhancement:

$$\mathcal{L}_c = D_c + \lambda_e \hat{H}(Y_c|Y_t), \qquad \mathcal{L}_r = D_r + \lambda_r \hat{H}(Y_r) \tag{5}$$

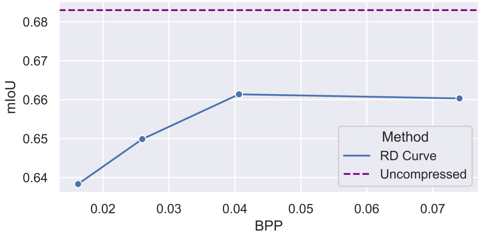
EXPERIMENTS

- Semantic segmentation: Cityscapes; object detection: COCO 2017
- Train the base independently: $f_b(\cdot)$ and $g_b(\cdot)$ under various λ_b
- Pick single (good) base representation Y_b for conditional/residual setting
- Upper baseline: reconstruction task with no side information
- Lower baseline: upper baseline + base rate $\hat{H}(Y_b) + \hat{H}(Y_e)$



(a) Scalable reconstruction

	Conditional	Residual
BD-Rate	-16.56%	-14.6%
Utilization	43.01%	37.91%

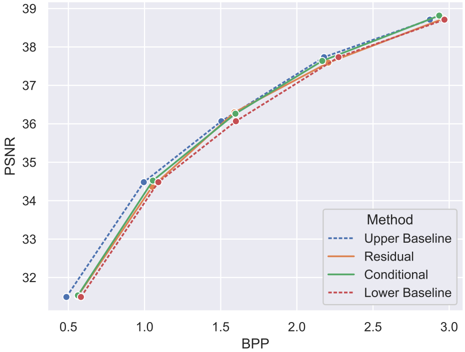


(b) Semantic segmentation

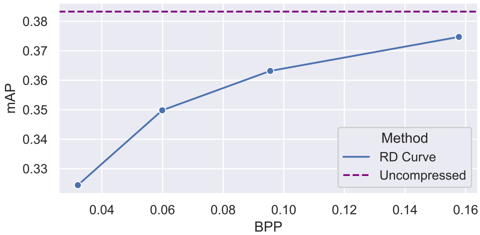
Figure 3: Rate-distortion curves for Cityscapes.

EXPERIMENTS

	Conditional	Residual
BD-Rate	-4.14%	-2.47%
Utilization	49.24%	29.32%



(a) Scalable reconstruction



(b) Object detection

Figure 4: Rate-distortion curves for COCO.

CONCLUSION

- Conditional and residual coding perform similarly using proposed design
- RD curves between presented baselines (operational bounds)
- Proposed conditional entropy model and small reconstruction penalty leads to improved utilization of side information

DERIVATIONS

Lossless lower bound:

$$\begin{aligned} H(Y_c) &\leq H(Y_c) + H(Y_t|Y_c) = H(Y_c, Y_t) \\ &= H(Y_t) + H(Y_c|Y_t) \leq H(Y_b) + H(Y_c|Y_t). \end{aligned} \tag{6}$$

Lossless upper bound:

$$\begin{aligned} H(Y_b) + H(Y_c|Y_t) &= H(Y_b) + H(Y_c) - I(Y_c; Y_t) \\ &\leq H(Y_b) + H(Y_c). \end{aligned} \tag{7}$$

Residual and conditional coding:

$$H(X|X_p) = H(X_r + X_p|X_p) = H(X_r|X_p) \tag{8}$$

$$= H(X_r) - I(X_p; X_r) \leq H(X_r) = H(X|X_p) + I(X_p; X_r). \tag{9}$$