Hardware Reverse Engineering Workshop (HARRIS 2025)
17.-18. March 2025 Bochum, Germany

# Die-Polygon-Capturing: From Hobbyist Hack to Automated Microchip Reverse Engineering Tool

## A proof of concept for automating die-polygon-capturing using deep neural networks

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PLOS | COMPUTATIONAL BIOLOGY

RESEARCH ARTICLE

# Could a Neuroscientist Understand a Microprocessor?

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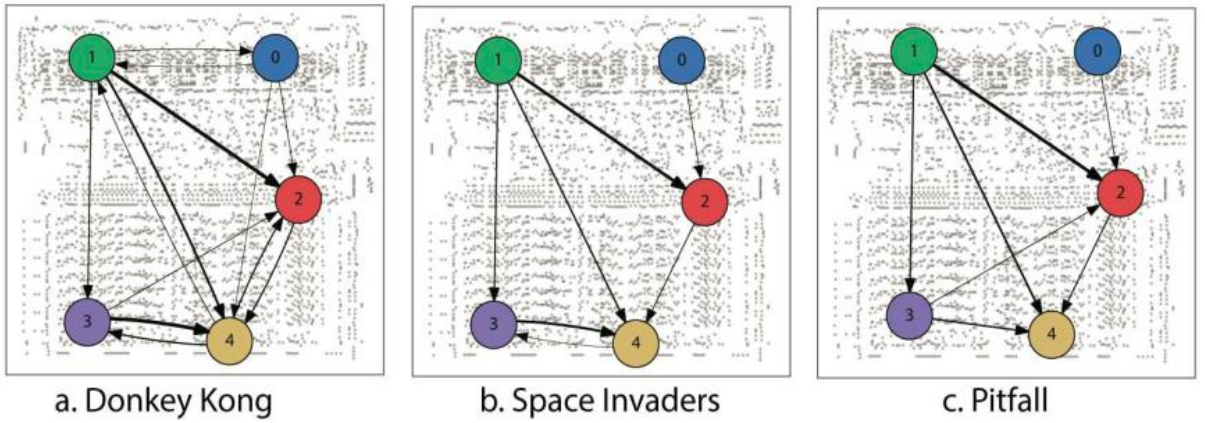



Jonas E, Kording KP (2017) Could a Neuroscientist Understand a Microprocessor? PLoS Comput Biol 13(1): e1005268. doi:10.1371/ journal.pcbi.1005268

# Importance of Reverse Engineering Microchips

*Some examples*

- Enhancing safety and privacy
- Innovative industry influence
- Historical preservation
- Intellectual property infringement detection

# A Challenge

*A challenge in reverse-engineering microchips*

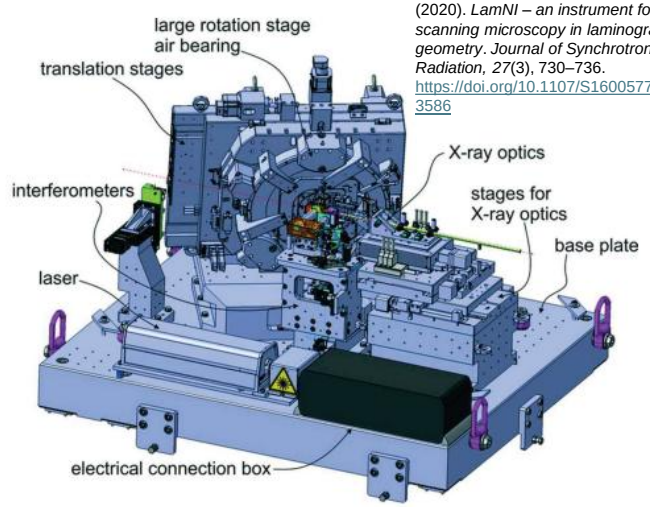
Precisely segmenting the
distinct patterns that are
printed on the silicon base layer
of the chip.

# Current Technology and Industry

- Focused Ion Beam (FIB) milling
- Ptychographic X-ray Computed Tomography (PXCT)
- Expensive machinery
- Growing trend of chip designs diversity
- Other approaches to reverse engineering?

Intlvac Thin Film Corporation. (n.d.). *Nanoquest System – Ion Beam Sputtering and Etching Platform*. Retrieved March 22, 2025, from https://www.intlvac.com/Systems/Intlvac-Systems

*(a) FIB*

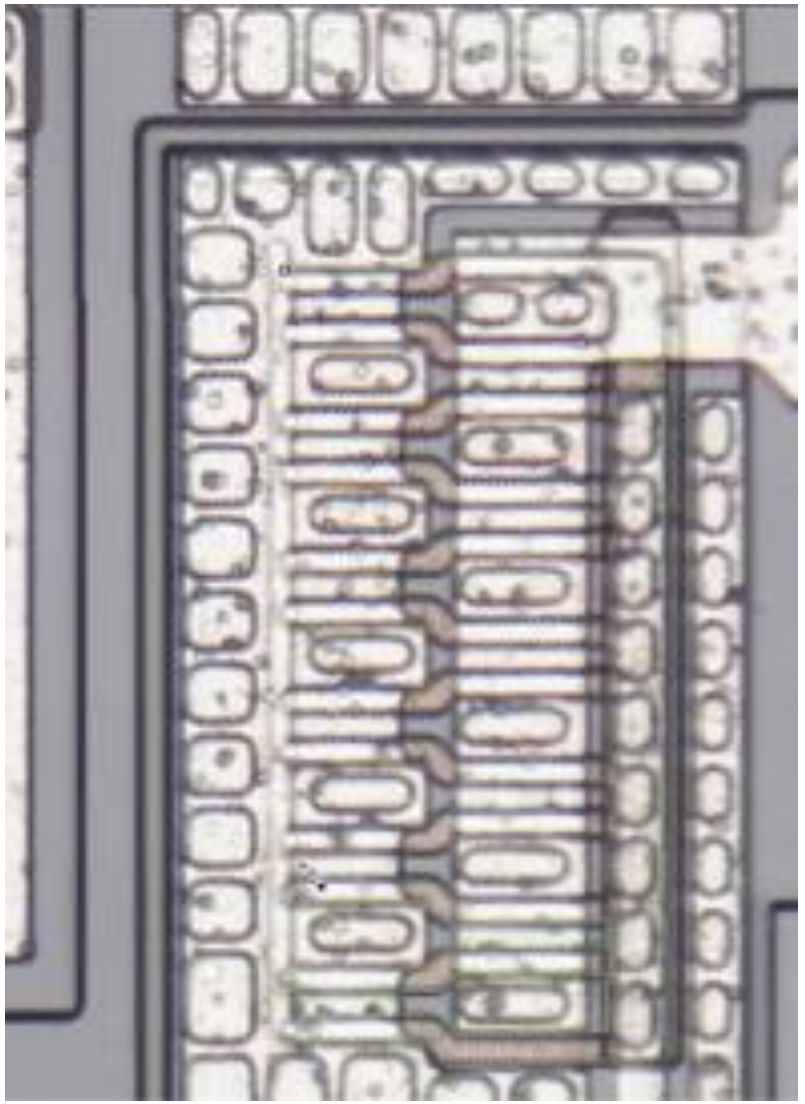



Holler, M., Odstrčil, M., Guizar-Sicairos, M., Lebugle, M., Frommherz, U., Lachat, T., Bunk, O., Raabe, J., & Aeppli, G. (2020). *LamNI – an instrument for X-ray scanning microscopy in laminography geometry*. *Journal of Synchrotron Radiation, 27*(3), 730–736. https://doi.org/10.1107/S1600577520003586

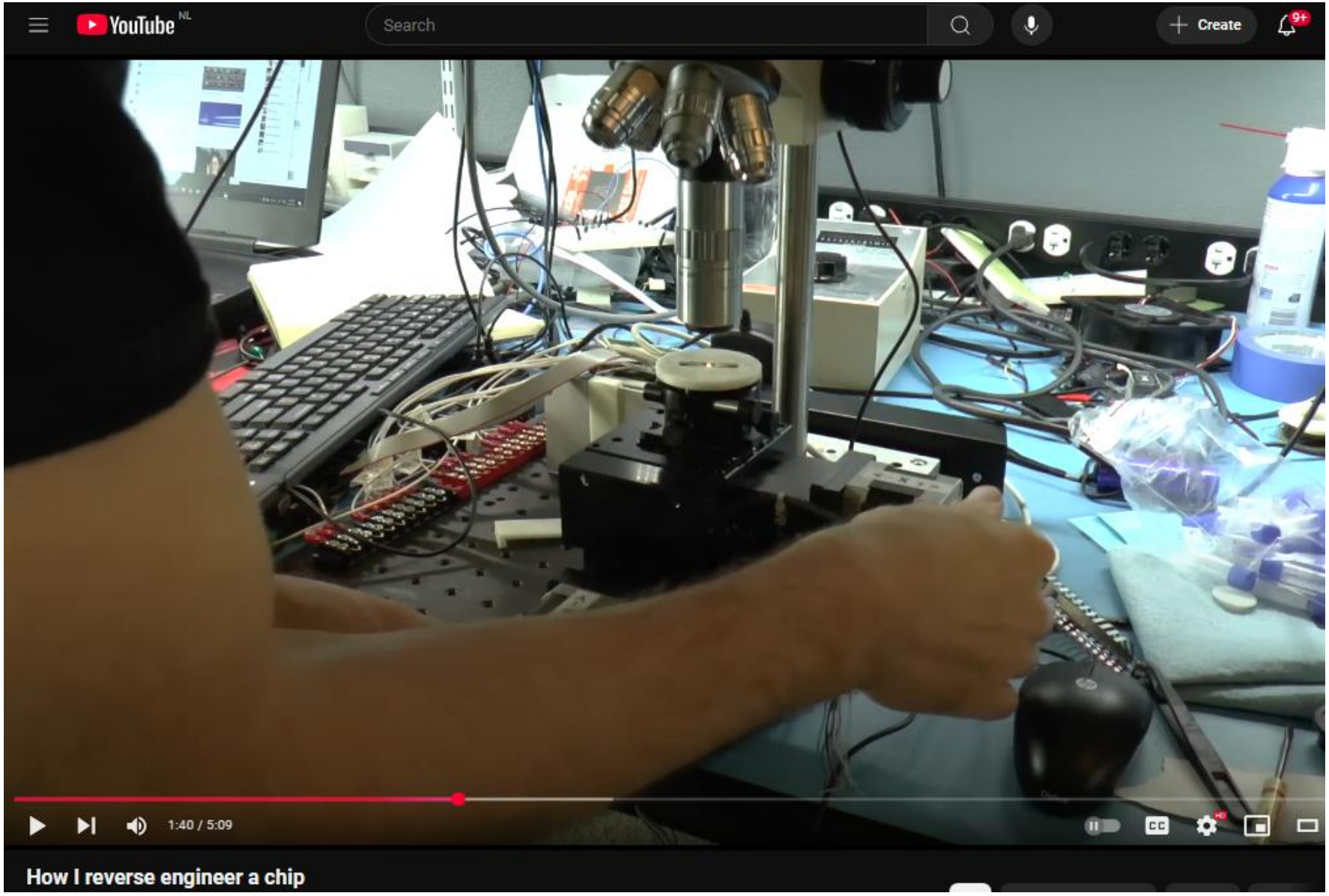
*(b) PXCT*

# Another Approach

- Die-Polygon-Capturing (DPC)
- Effective for simple microchips
- Hobbyist community of engineers
- Cheaper and more accessible
- No scientific literature
- Time-consuming for a person with expert knowledge



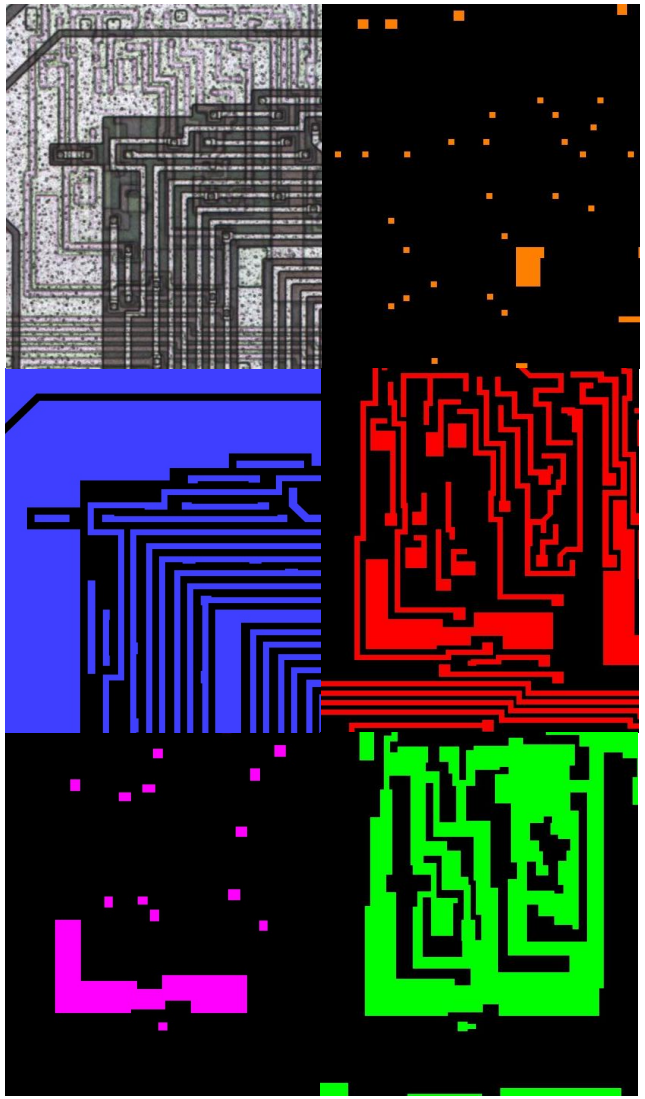
Robert Baruch, “Reverse Engineering a Simple CMOS Chip,” October 11, 2018, https://www.youtube.com/watch?v=FMdYuGpPicw.



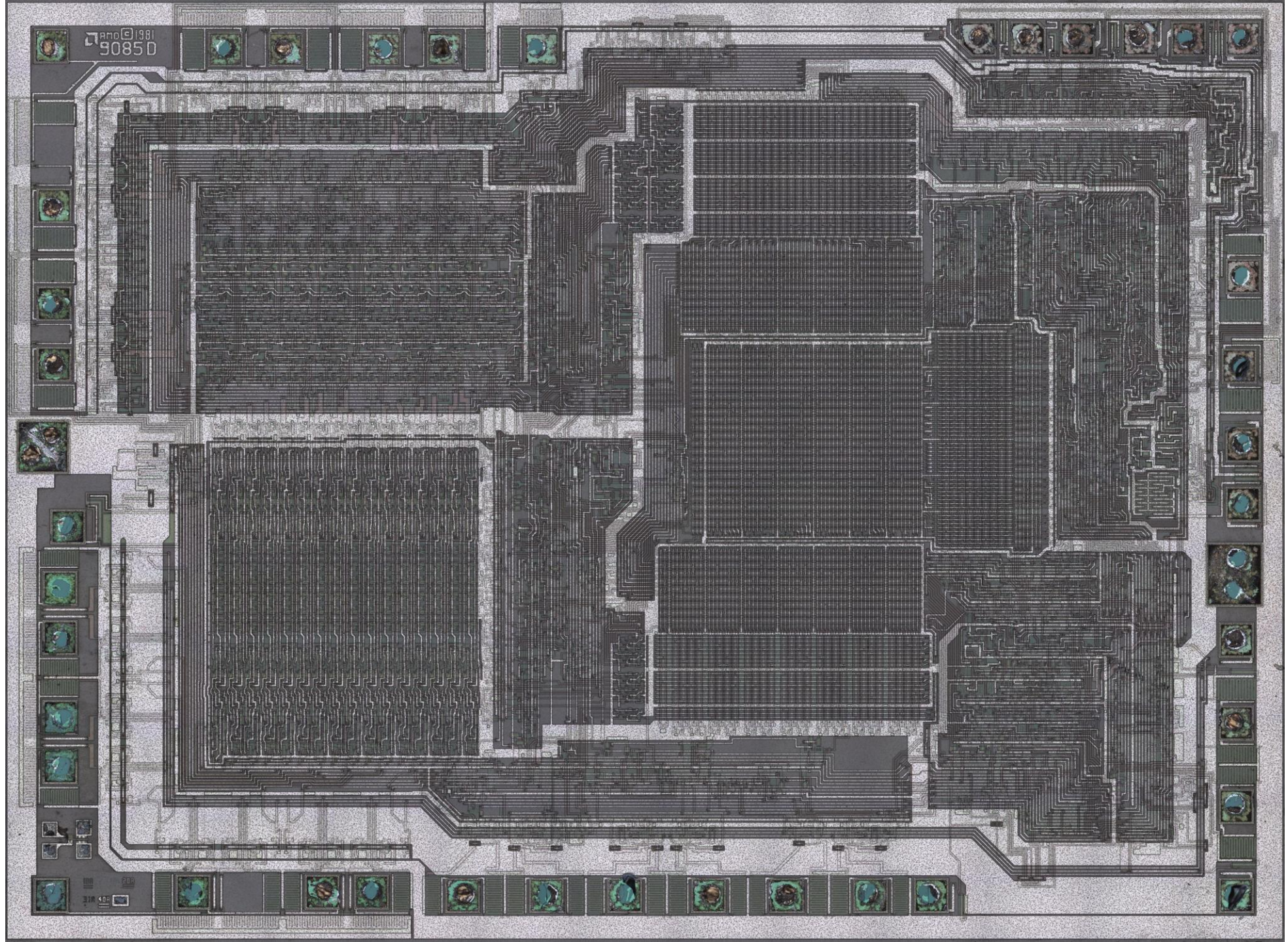

Robert Baruch, “How I Reverse Engineer a Chip,” April 23, 2017, https://www.youtube.com/watch?v=r8Vq5NV4Ens.

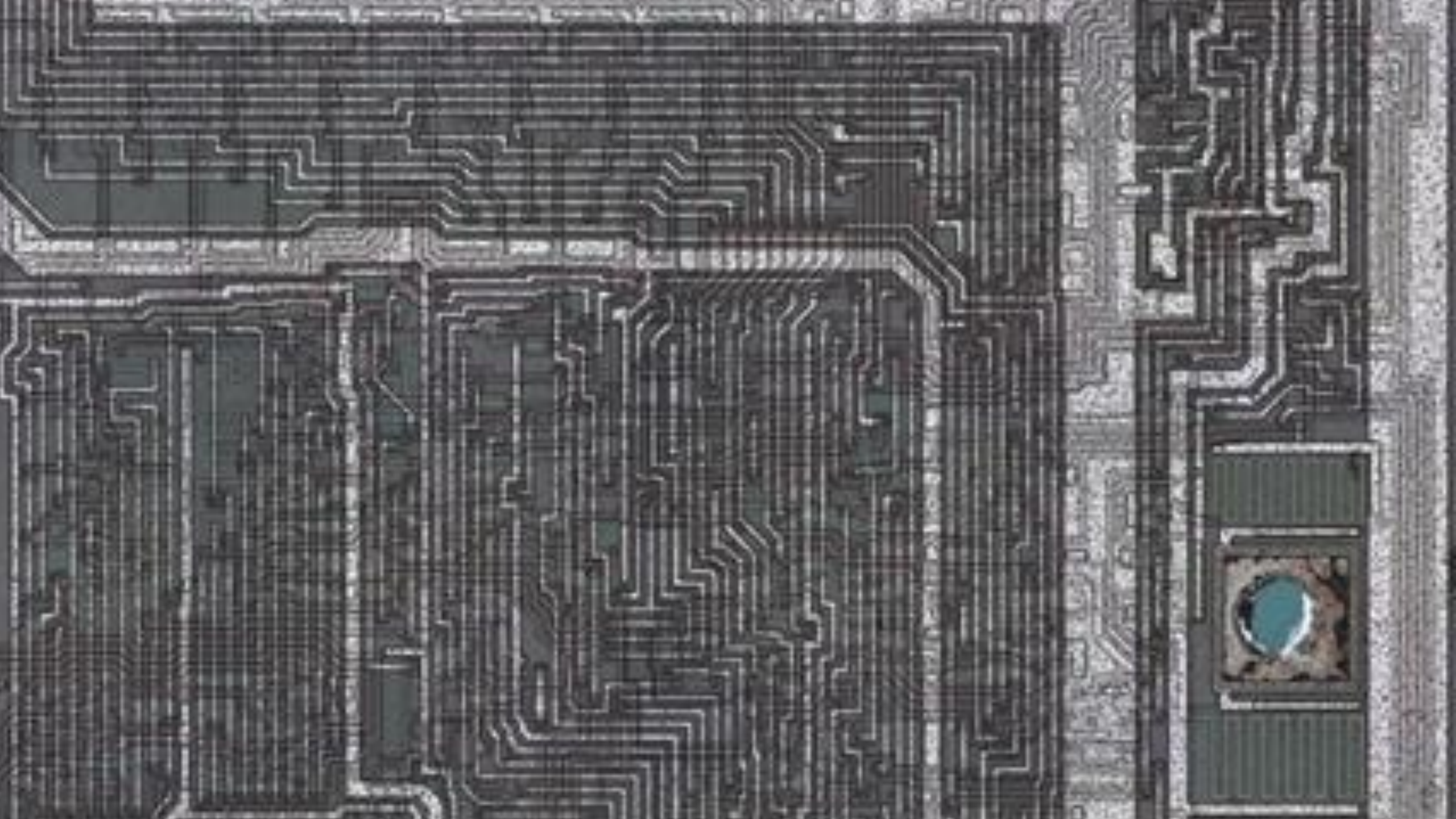
# The Dataset

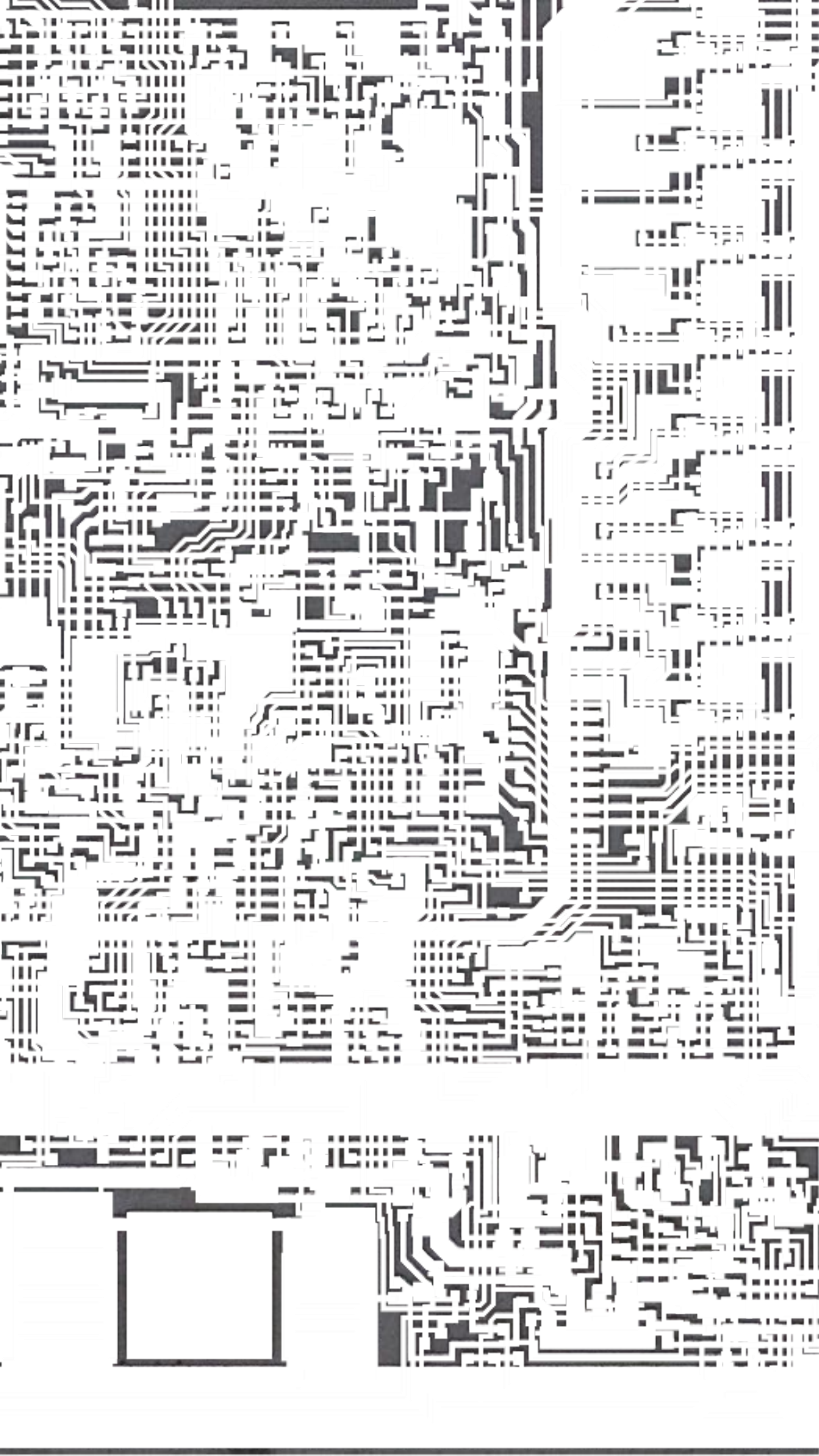
- Blog on Visual6502.org
- AMD 9085D CPU Chip
- Image per label



Visual 6502 Project. *8085 Die Shots*.
Retrieved from http://visual6502.org/images/pages/8085_die_shots.html


AMD 1981
9085 D





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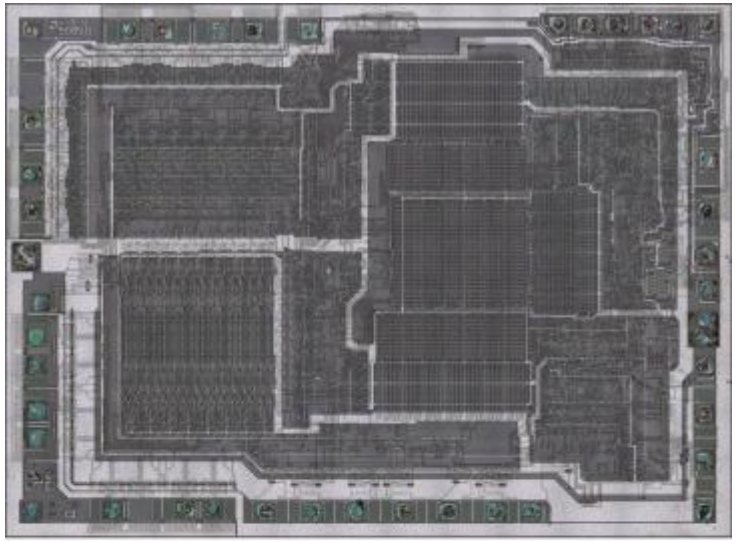
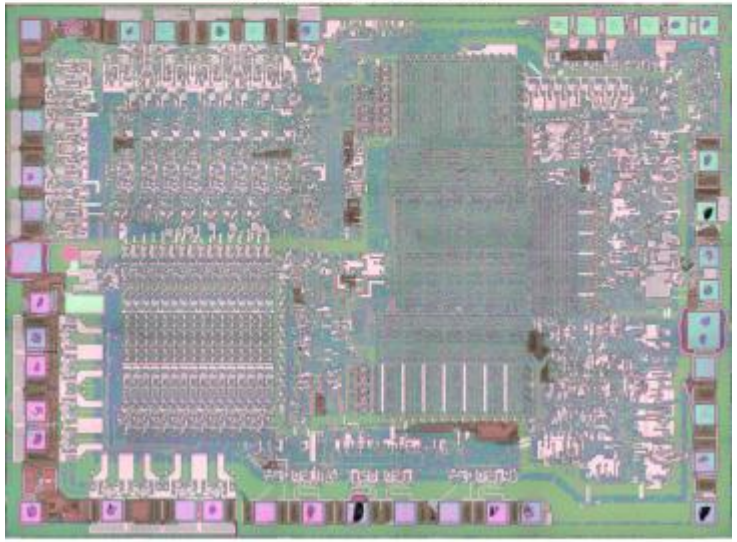


(a) Surface-level image.



(b) Substrate-level image.

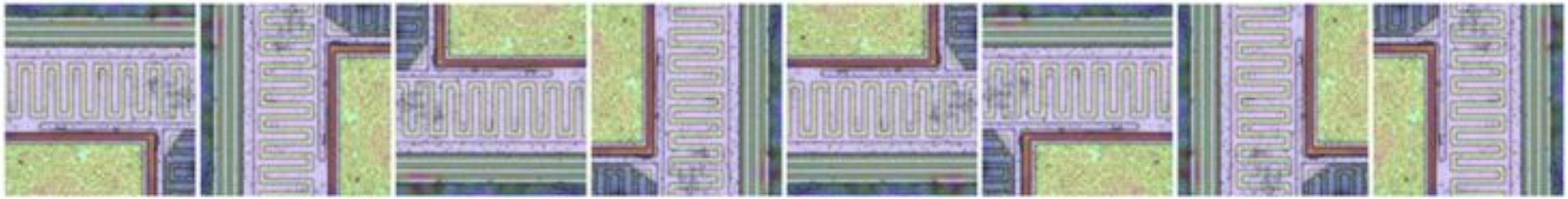
Visual 6502 Project. *8085 Die Shots*.
Retrieved from http://visual6502.org/images/pages/8085_die_shots.html

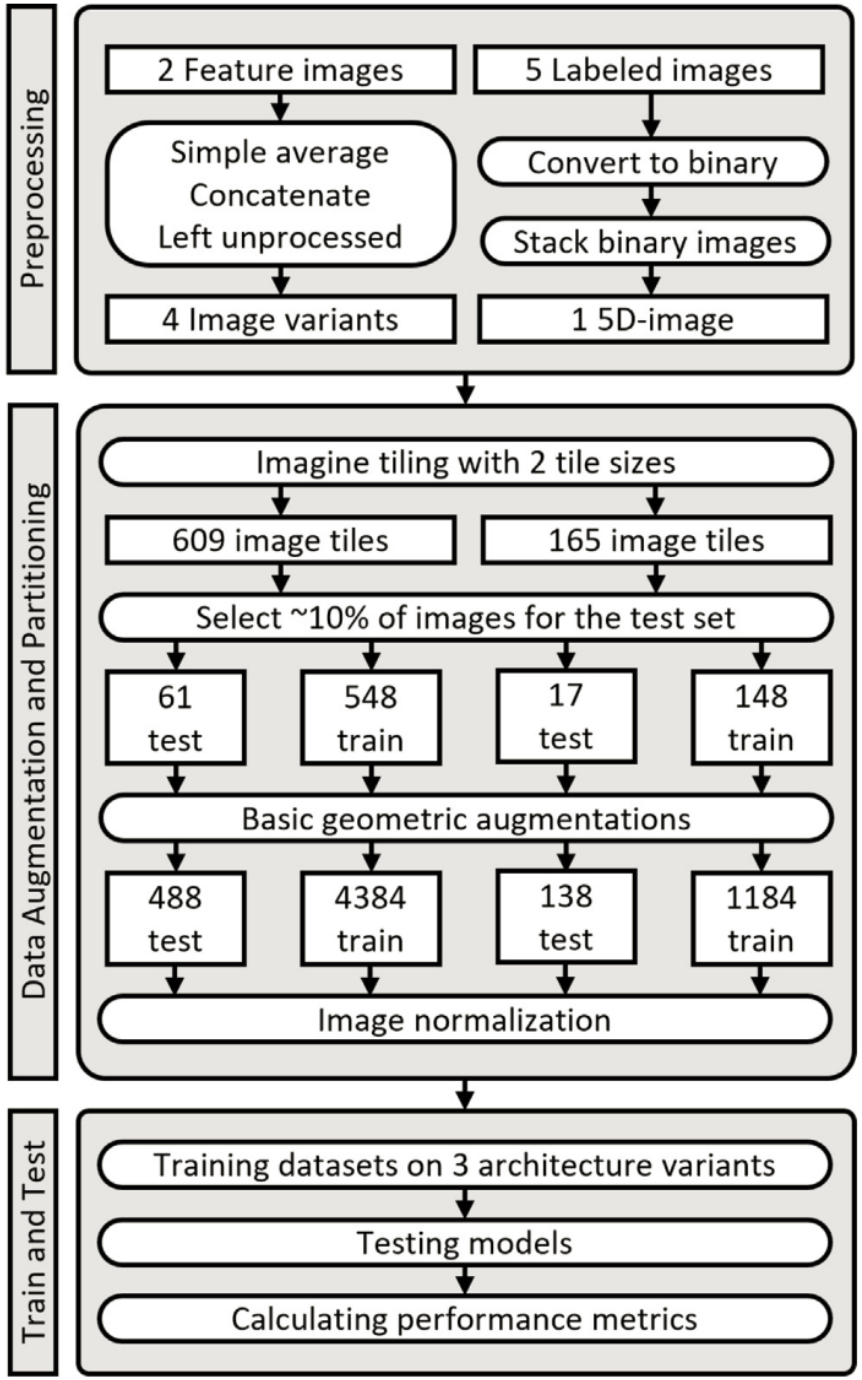
# Automating a Time-Consuming Segmentation

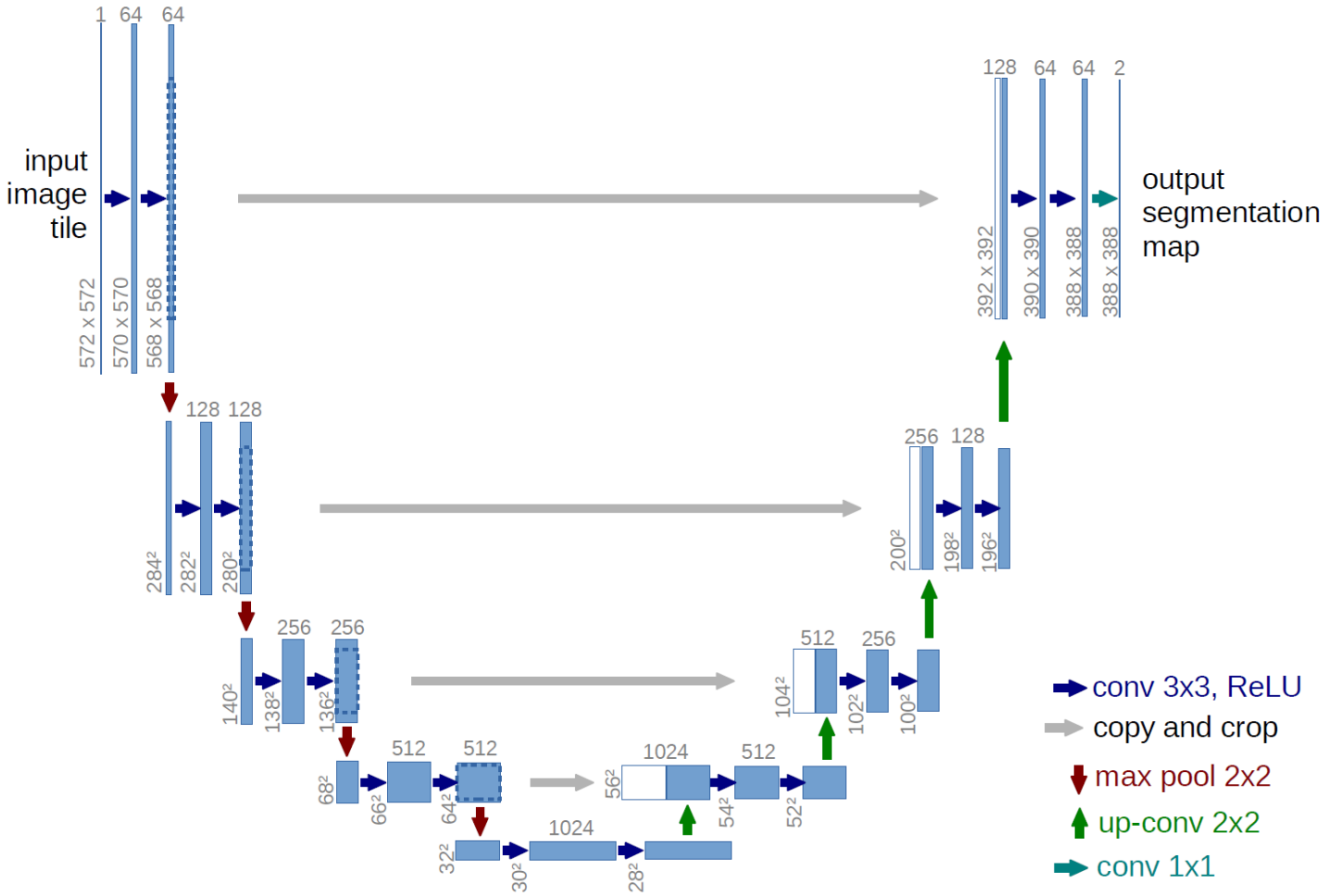
- Comparison of neural network model configurations

| 3 | 4 | 2 |
| --- | --- | --- |
| Types of U-Net architectures | Types of dataset preprocessing | Image sizes |

- Extensive data augmentation to enlarge the dataset






Ronneberger, O., Fischer, P., & Brox, T. (2015). *U-Net: Convolutional Networks for Biomedical Image Segmentation*. *arXiv preprint* arXiv:1505.04597. https://doi.org/10.48550/arXiv.1505.04597

| PP | Arch | Size | Intersection over Union | | | | | F-beta (0.707) | | | | | Training Time (h) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | B | D | M | P | V | B | D | M | P | V | |
| CC | OG | 256 | 71.38 | 94.47 | 95.84 | 87.82 | 85.55 | 83.30 | 97.03 | 97.78 | 93.45 | 92.64 | 0.83 |
| | | 512[a] | 44.71 | 85.58 | 92.87 | 81.90 | 63.30 | 65.74 | 94.08 | 97.06 | 90.85 | 78.56 | 0.36 |
| | P2 | 256 | 58.37 | 94.67 | 96.06 | 87.00 | 85.87 | 79.18 | 97.41 | 98.08 | 92.71 | 93.21 | 0.74 |
| | | 512[a] | 21.65 | 87.53 | 93.84 | 82.07 | 41.25 | 43.46 | 94.25 | 96.96 | 90.24 | 65.18 | 0.33 |
| | R | 256[a] | 75.52 | 94.83 | 96.00 | 88.11 | 86.39 | 86.44 | 97.48 | 98.09 | 93.48 | 92.22 | 0.58 |
| | | 512[a] | 63.19 | 92.42 | 95.27 | 86.03 | 77.48 | 78.18 | 96.29 | 97.57 | 92.67 | 87.31 | 0.49 |
| JDE | OG | 256 | 77.06 | 94.54 | 79.29 | 87.63 | 79.09 | 87.92 | 97.35 | 88.88 | 93.94 | 89.18 | 0.81 |
| | | 512 | 59.87 | 91.78 | 78.45 | 83.17 | 72.03 | 78.45 | 95.26 | 87.44 | 91.76 | 83.47 | 0.72 |
| | P2 | 256 | 74.15 | 94.41 | 72.64 | 87.43 | 76.94 | 84.29 | 97.02 | 84.24 | 93.37 | 87.56 | 0.72 |
| | | 512 | 41.61 | 90.61 | 70.13 | 82.44 | 44.19 | 63.98 | 94.72 | 83.65 | 90.96 | 68.23 | 0.65 |
| | R | 256[a] | 73.32 | 94.77 | 77.60 | 87.67 | 79.23 | 87.16 | 97.49 | 87.17 | 93.87 | 89.14 | 0.56 |
| | | 512[a] | 56.06 | 91.52 | 77.01 | 84.14 | 72.14 | 77.81 | 95.35 | 86.25 | 90.72 | 82.58 | 0.46 |
| JDI | OG | 256 | 35.75 | 85.96 | 96.13 | 82.13 | 88.43 | 58.08 | 93.61 | 97.97 | 90.17 | 93.59 | 0.81 |
| | | 512 | 3.33 | 79.82 | 96.05 | 79.00 | 85.57 | 9.31 | 90.52 | 97.81 | 88.25 | 91.76 | 0.72 |
| | P2 | 256 | 18.15 | 77.94 | 95.20 | 76.77 | 78.60 | 37.30 | 88.40 | 97.78 | 87.86 | 87.05 | 0.71 |
| | | 512 | 0.00 | 63.82 | 95.29 | 65.89 | 47.33 | 0.00 | 80.24 | 97.74 | 83.56 | 67.77 | 0.65 |
| | R | 256[a] | 38.16 | 86.41 | 96.24 | 79.31 | 87.68 | 60.89 | 92.80 | 98.21 | 90.38 | 93.26 | 0.55 |
| | | 512[a] | 4.21 | 79.21 | 95.76 | 77.51 | 80.04 | 11.55 | 88.79 | 97.83 | 88.30 | 89.43 | 0.46 |
| SA | OG | 256 | 75.36 | 93.39 | 95.16 | 87.02 | 85.79 | 86.24 | 96.40 | 97.45 | 92.83 | 92.60 | 0.81 |
| | | 512 | 57.94 | 90.97 | 94.61 | 84.53 | 76.54 | 75.03 | 95.28 | 97.18 | 91.56 | 87.34 | 0.72 |
| | P2 | 256 | 70.06 | 93.59 | 95.33 | 87.26 | 83.82 | 83.74 | 96.82 | 97.73 | 93.43 | 91.78 | 0.72 |
| | | 512 | 41.74 | 89.45 | 93.99 | 83.09 | 69.94 | 64.41 | 94.75 | 96.91 | 90.54 | 83.63 | 0.66 |
| | R | 256[a] | 70.41 | 93.52 | 95.00 | 87.19 | 83.18 | 83.97 | 96.68 | 97.32 | 93.54 | 91.55 | 0.55 |
| | | 512[a] | 51.38 | 88.88 | 94.04 | 82.58 | 74.03 | 69.39 | 94.23 | 97.19 | 90.93 | 85.56 | 0.46 |

[a] Denotes models utilizing half of the original filter count.

# Proof of Concept

- Top performing model configurations show promising results for automation

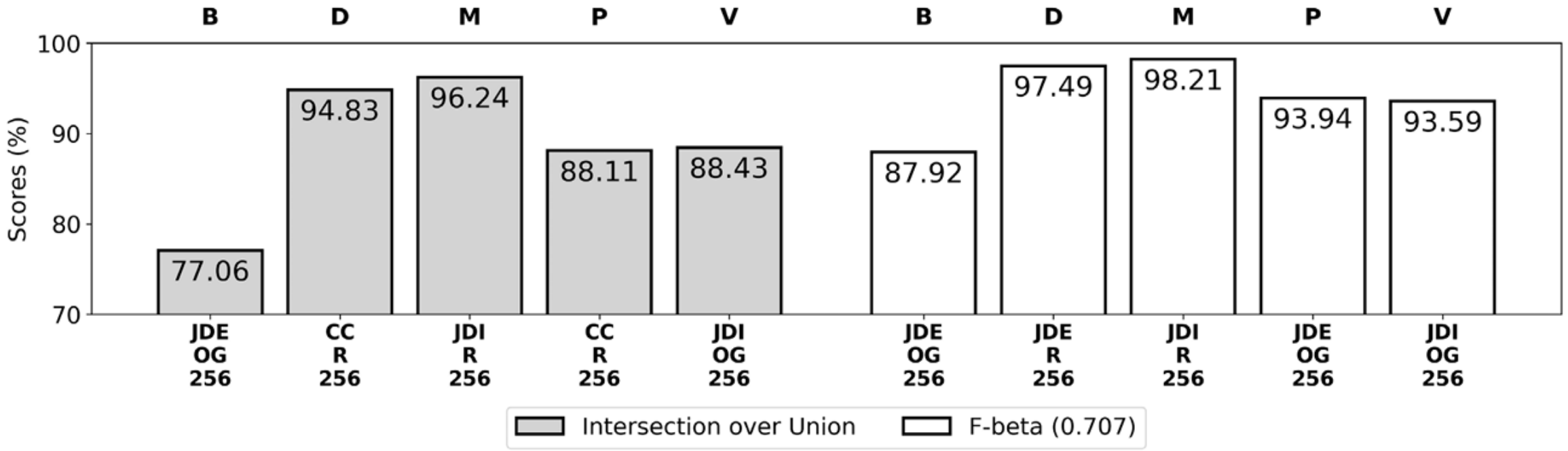
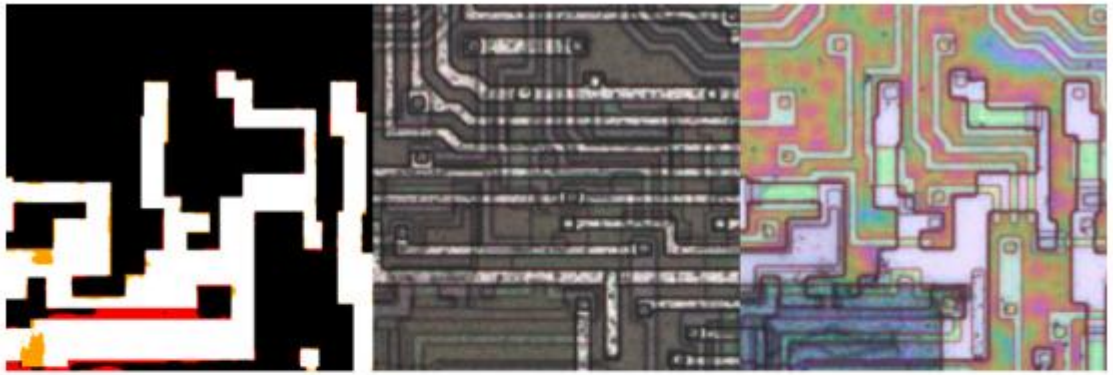


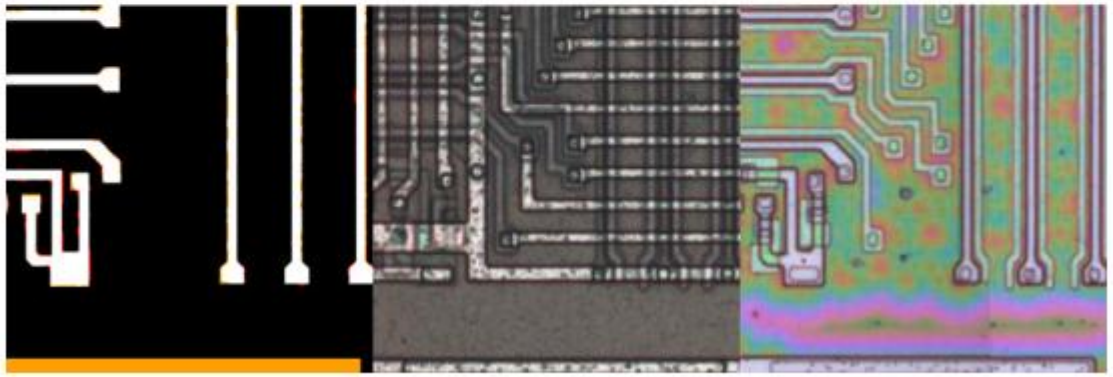

**Fig. 10.** Bargraph showing the IoU and F-beta (0.707) scores (rounded to 2 d.p.) of the top-performing model settings across labels.

- Error analysis

Largest error-clusters for the **diffusion** label compared to their input (concatenated).

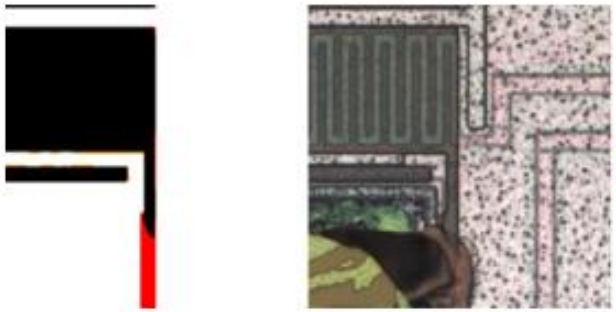


FP-cluster (cs = 705)



FN-cluster (cs = 2717)

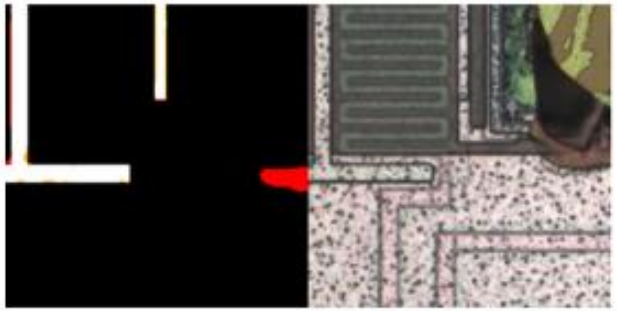
Largest error-clusters for the **metal** label compared to their input.



FP-cluster (cs = 874)

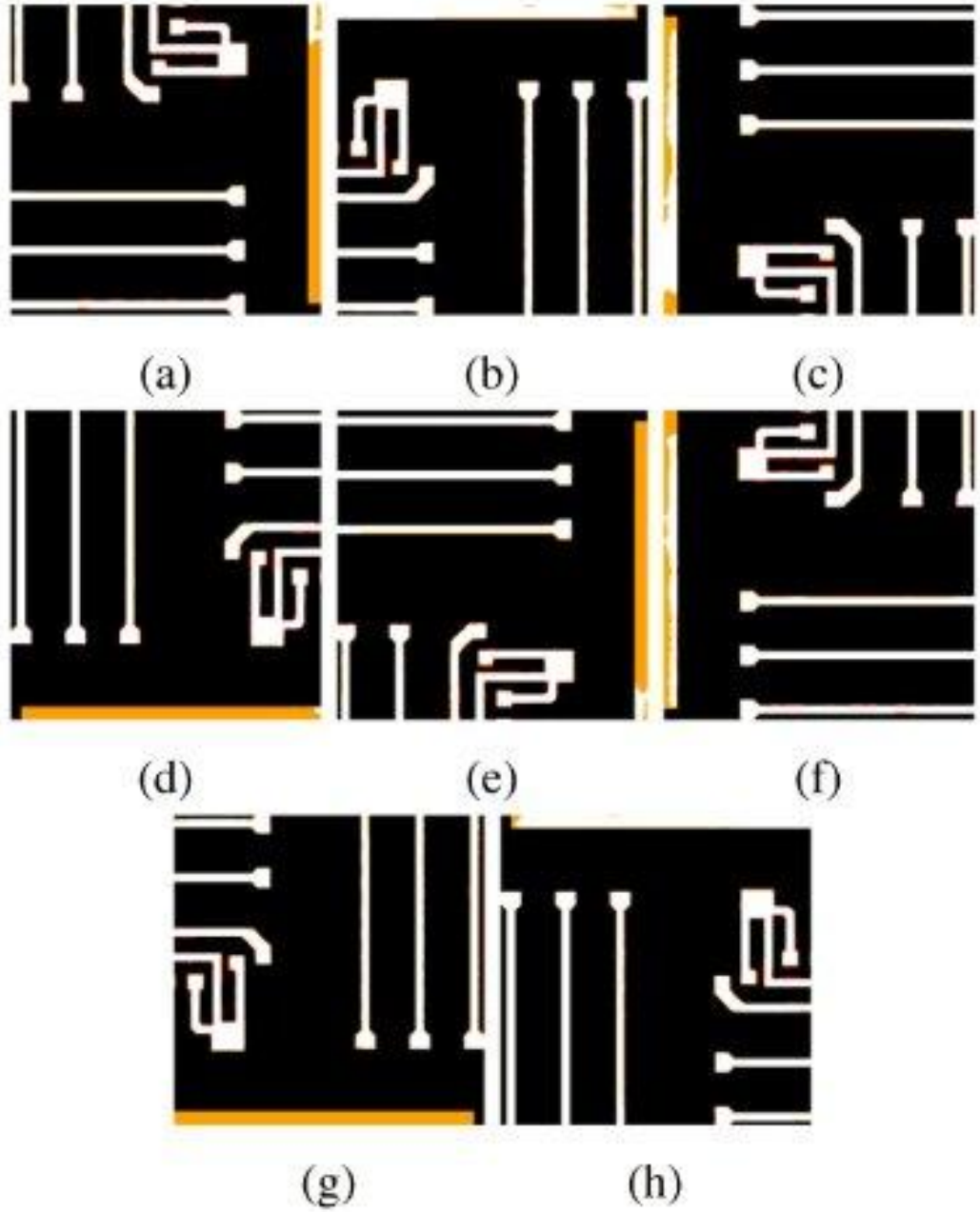
FN-cluster (cs = 508)

Largest error-clusters for the **polysilicon** label compared to their input (concatenated).



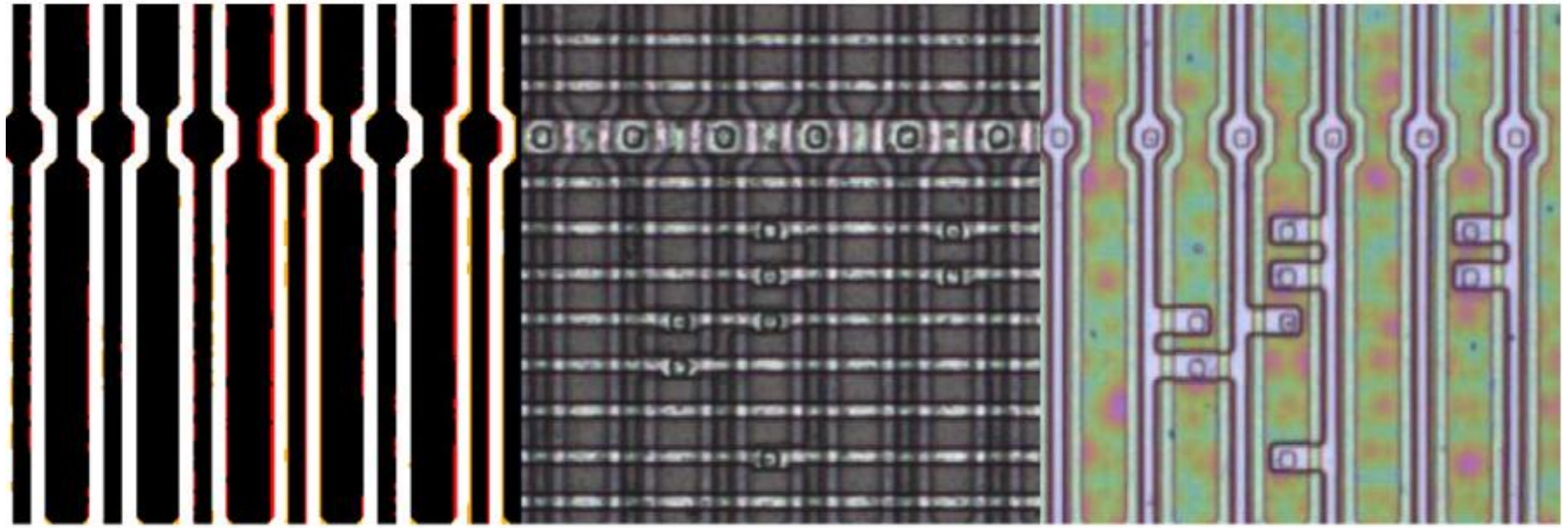
FP-cluster (cs = 643)

FN-cluster (cs = 741)



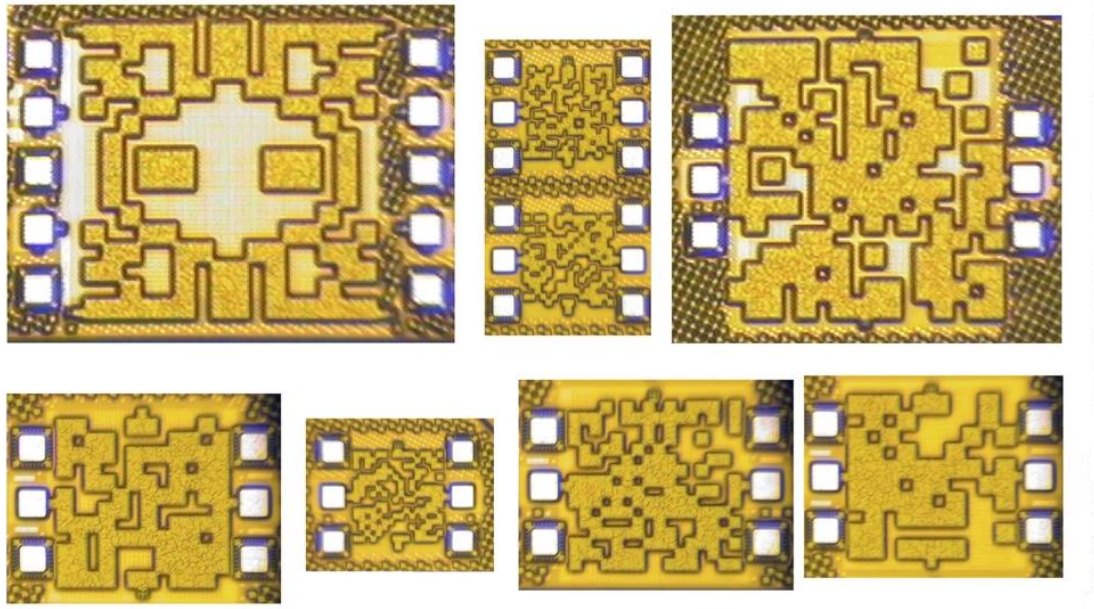

Confusion images of the same augmentation set in the diffusion label.

- Error analysis



# Limitations & Future Work

- Generalization
- Encourage to label and open-source microchip designs.
- Unsupervised techniques
- Inspire future research



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# Deep-learning enabled generalized inverse design of multi-port radio-frequency and sub-terahertz passives and integrated circuits

Emir Ali Karahan ✉, Zheng Liu, Aggraj Gupta, Zijian Shao, Jonathan Zhou, Uday Khankhoje & Kaushik Sengupta

*Nature Communications* **15**, Article number: 10734 (2024) | Cite this article

Karahan, E.A., Liu, Z., Gupta, A. *et al.* Deep-learning enabled generalized inverse design of multi-port radio-frequency and sub-terahertz passives and integrated circuits. *Nat Commun* **15**, 10734 (2024). https://doi.org/10.1038/s41467-024-54178-1

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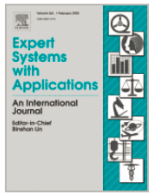

Simple integrated circuit reverse-engineering with deep learning: A proof of concept for automating die-polygon-capturing


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