Power Electronics Turing Test: A Path Toward Strong AI in Power Electronics

Minjie Chen, Dak C. Cheng
Department of Electrical and Computer Engineering
Andlinger Center for Energy and the Environment
Princeton University, United States
Email: {minjie, dc2326}@princeton.edu

***Abstract*—This paper presents a hypothetical Turing test in power electronics, leveraging structured computer vision as a step towards domain-specific artificial general intelligence (AGI). To illustrate the key principles of such a power electronics Turing test, we developed PowerVision, a computer vision framework designed to teach machines to understand schematic drawings. PowerVision comprises four key components: 1) ComponentNet: an image database for component recognition; 2) CircuitNet: an image database for schematic recognition; 3) NetlistMaker: a schematic recognition tool that converts human-readable schematics into netlists for SPICE simulations; and 4) NetlistClassifier: a circuit classification tool that can categorize different power electronics circuits based on machine-generated netlists. The PowerVision platform can facilitate the learning of power electronics fundamental principles by large-scale AGI models through human-accessible information including texts, schematics, computer simulations, and experimental results, ultimately enabling machines to comprehend power electronics.**

***Index Terms*—artificial general intelligence, Turing test, machine learning, computer vision, netlists, SPICE simulation**

I. Introduction

Artificial general intelligence (AGI), a type of AI that can perform as well as or better than human and interact with human across a wide range of cognitive tasks, holds great potential engineering design [1]–[4]. A critical aspect of human learning in power electronics is the coherent integration of vast amounts of information in various formats, such as text descriptions, schematics, computer simulations, and images in textbooks, scientific publications, and engineering handbooks. For domain specific AGI models to assist human designers or to perform automated design tasks, they must be capable of learning from human-accessible information.

Training AGI models (e.g., ChatGPT) to understand domain knowledge is challenging because of the lack of good training data and domain-specific knowledge abstraction. There is no large-scale high-quality database (such as those in [5], [6]) for AGI models to learn about power electronics. Modern large language models (e.g., ChatGPT-3.5, Google Gemini, Github Copilot) understand texts and netlists, but there is no database for them to understand the connections among texts, netlists, and drawings. This paper tries to address the above challenges by developing **PowerVision**, an end-to-end framework for exploring AGI in power electronics, comprising:

1) **ComponentNet**: a hand-collected image database with 2,561 power electronics component drawings;
2) **CircuitNet**, a hand-collected image database with 200 hand-labeled power electronics circuit schematics;
3) **NetlistMaker**, an automated schematic recognition tool which converts human-readable schematics;
4) **NetlistClassifier**, an automated circuit classification tool which can classify different power electronics circuits based on the machine-readable netlists.
5) **NetlistSimulator**, an automated circuit simulator which allows the AGI model to run SPICE simulations based on the netlist created.

All data and tools are open-sourced in GitHub[1].

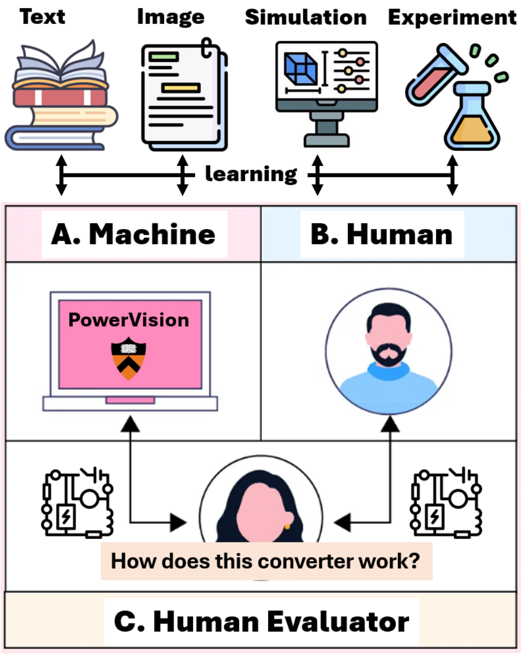


Fig. 1. A power electronics Turing test revolves around both machines and humans establishing understandings about schematic drawings and circuit functions, subsequently engaging in communication with a human evaluator.

II. Power Electronics Turing Test

The Turing test, initially proposed as the imitation game by Alan Turing in 1950 [7], assesses a machine's capability to demonstrate intelligent behavior comparable to, or

[1] PowerVision: https://github.com/minjiechen/PowerVision

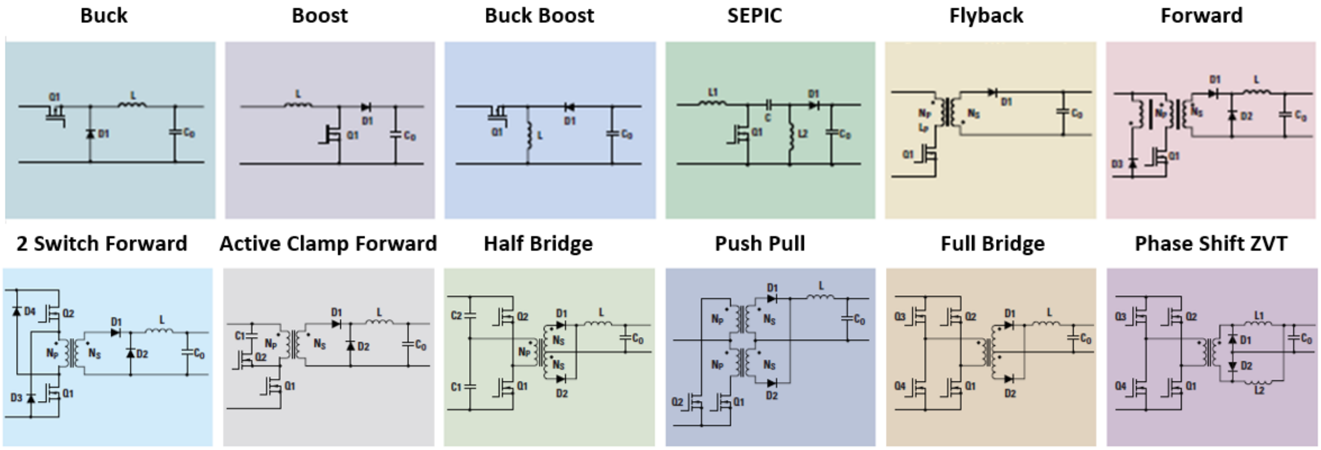
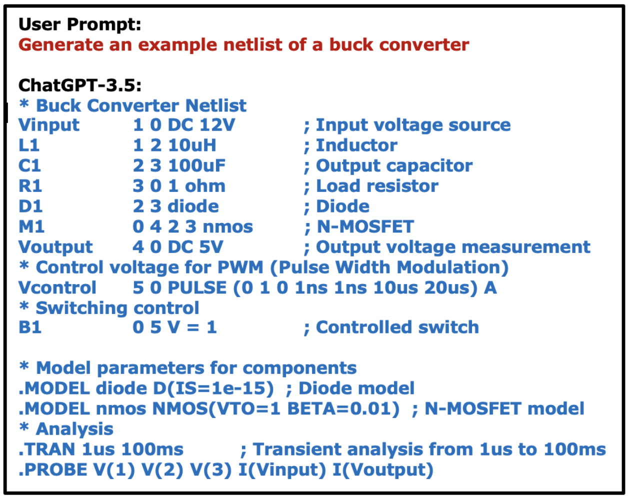


Fig. 2. Power electronics topologies and their operational principles: https://www.ti.com/lit/ml/sluw001g/sluw001g.pdf. The majority of practical power electronics converters are derived from these topologies. Each of these topologies can serve as a basis for conducting a domain-specific Turing test in power electronics. Comprehending the operational principles of these topologies constitutes the initial step towards achieving AGI in power electronics.

indistinguishable from, that of a human. A more specific interpretation of the Turing test focuses on a computer's ability to successfully mimic human behavior within a designated domain of human intelligence, such as power electronics. Illustrated in Fig. 1, the hypothetical power electronics Turing test entails a human evaluator posing questions to both a human expert and a computer model, seeking explanations of schematic drawings. The evaluator remains unaware of which conversational partner is the machine, and all participants are isolated from each other. The conversation begins with a schematic drawing as input and culminates in a human-language description of the schematic or a response to a specific inquiry. If the evaluator cannot reliably distinguish between the machine and the human, the machine is deemed to have successfully passed the test.

Figure 2 showcases twelve main-stream dc-dc power electronics topologies commonly employed in practical applications, comprising: Buck, Boost, Buck-Boost (Inverting), SEPIC, Flyback, Forward, 2 Switch Forward, Active Clamp Forward, Half Bridge Push Pull, and Full Bridge Phase Shift ZVT. A significant portion of power electronic systems are designed based on these switching cells. An average power electronics engineer possesses the ability to swiftly classify these topologies from schematic drawings and articulate their operational principles using concise natural language sentences. In a power electronics Turing test, the evaluator might present a drawing of a power converter to both the human expert and the computer model, asking, **"Is this converter a pulse-width-modulated (PWM) converter? How does it work? Can you simulate it, and describe how it works?"** If the evaluator cannot discern between the responses from the machine and the human expert, the machine would be considered to have successfully passed the specific test.

A machine needs to be trained using data. While the learning process for human and machine experts may differ, the data used for training should be similar and inclusive of widely available, well-documented human-accessible information sources of high quality. Establishing an effective framework for machines to comprehend human-accessible information is pivotal for developing a domain-specific AGI capable of assisting power electronics design.


```
User Prompt:
Generate an example netlist of a buck converter

ChatGPT-3.5:
* Buck Converter Netlist
Vinput      1 0 DC 12V          ; Input voltage source
L1          1 2 10uH            ; Inductor
C1          2 3 100uF           ; Output capacitor
R1          3 0 1 ohm           ; Load resistor
D1          2 3 diode           ; Diode
M1          0 4 2 3 nmos        ; N-MOSFET
Voutput     4 0 DC 5V           ; Output voltage measurement
* Control voltage for PWM (Pulse Width Modulation)
Vcontrol    5 0 PULSE (0 1 0 1ns 1ns 10us 20us) A
* Switching control
B1          0 5 V = 1           ; Controlled switch

* Model parameters for components
.MODEL diode D(IS=1e-15)  ; Diode model
.MODEL nmos NMOS(VTO=1 BETA=0.01)  ; N-MOSFET model
* Analysis
.TRAN 1us 100ms        ; Transient analysis from 1us to 100ms
.PROBE V(1) V(2) V(3) I(Vinput) I(Voutput)
```

Fig. 3. State-of-the-art AGI (e.g., ChatGPT-3.5 [8]) can generate commonly used power electronics netlists based on user prompts. However, it lacks the ability to interpret power electronics schematics or offer design guidance.

III. PowerVision Framework

As depicted in Fig. 3, contemporary AGI models like ChatGPT possess the ability to read and generate text as well as simple drawings [8]. However, they currently struggle with comprehending power electronics components or schematic drawings, primarily due to the absence of high-quality training data. Early attempts in power electronics topology synthesis lacked the support of modern artificial intelligence [9]. Modern tools for schematic to netlist conversion exist [10]–[12], but no effort has been shown to holistically integrate them into an end-to-end machine learning framework, such as the proposed Power Electronics Turing Test. This paper aims to bridge this gap and push toward strong AI in power electronics.

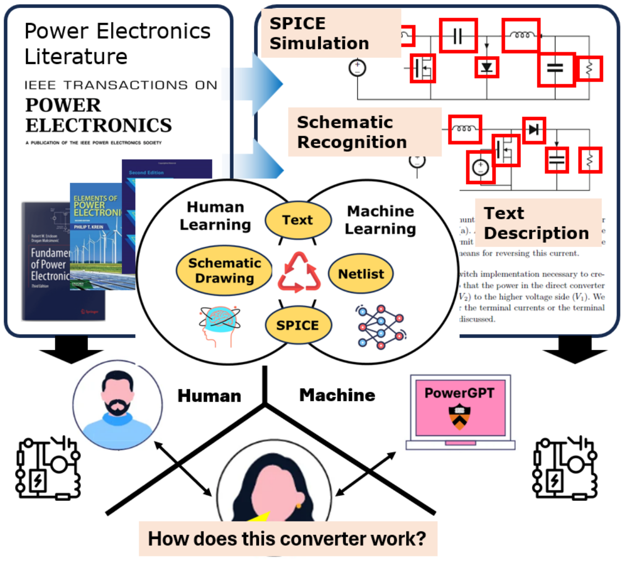


Fig. 4. The information flow for both human learning and machine learning in passing the Turing test involves processing text and SPICE information. While human learners excel at comprehending schematic drawings, machines demonstrate proficiency in interpreting structured data like netlists.

Figure 4 outlines the fundamental information flow of PowerVision. To effectively train large language models for human interaction, it's imperative to convert human knowledge into machine-readable data. Human-accessible information encompasses schematic drawings and textual descriptions, where the operational principles are articulated in natural language. Although qualitative and concise, human-accessible information can be prone to inaccuracies. Machine-accessible information in power electronics comprises netlists, component bill-of-materials, printed circuit boards (PCBs), and 3-D assembly drawings. Additionally, computers can engage circuit simulation tools to interpret netlists or utilize finite-element modeling (FEM) software like ANSYS to analyze physical components, PCBs, interconnects, and electromagnetic radiation. Machine-readable information is characterized by its quantitative, structured, complex, and precise nature.

At the core of PowerVision lies the circuit netlist, which is both human and machine accessible. The PowerVision platform encompasses the following five pivotal function blocks:

- **ComponentNet:** a large scale image database comprising thousands of images of different electrical components. Currently, the database contains 2,544 hand-collected and labeled component images in 11 categories, including "ac-src", "battery", "cap", "curr-src", "diode", "inductor", "resistor", "swi-ideal", "swi-real", "volt-src", "xformer".
- **CircuitNet:** a large scale image database comprising hundreds of power electronics schematics for netlist generation and classification. Currently the database contains 200 hand-collected and hand-labeled power electronics schematics.
- **NetlistMaker:** a computer program which reads the schematic drawing, then generates a netlist and an incident matrix based on the detected components and the wires that connect the components together.

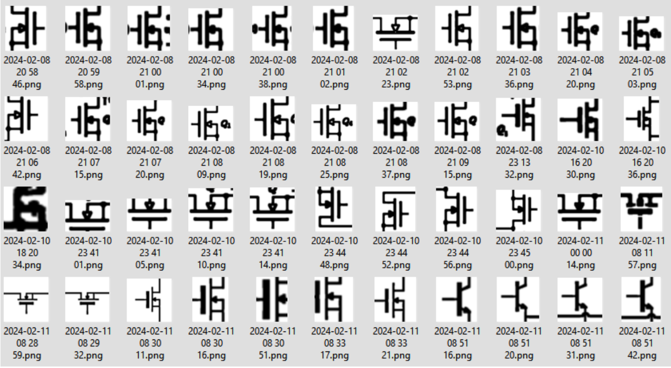


Fig. 5. The "switch-real" subfolder within the ComponentNet database comprises 202 images depicting various symbols for semiconductor switches. The complete database encompasses 2,544 manually collected component images categorized into 11 classes.

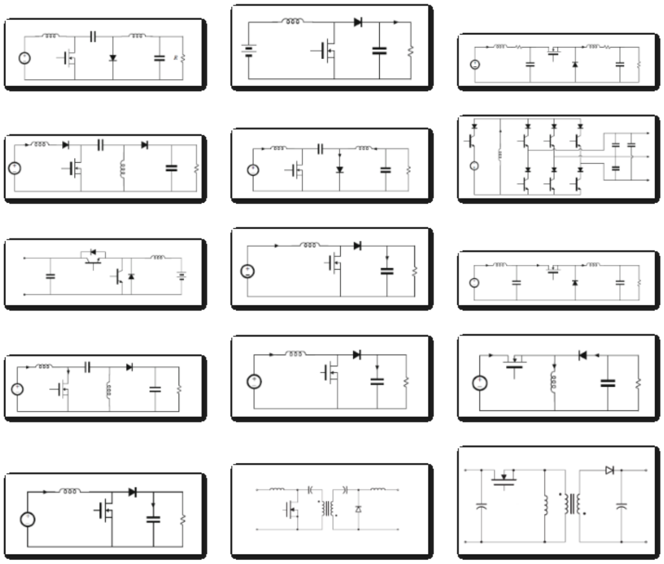
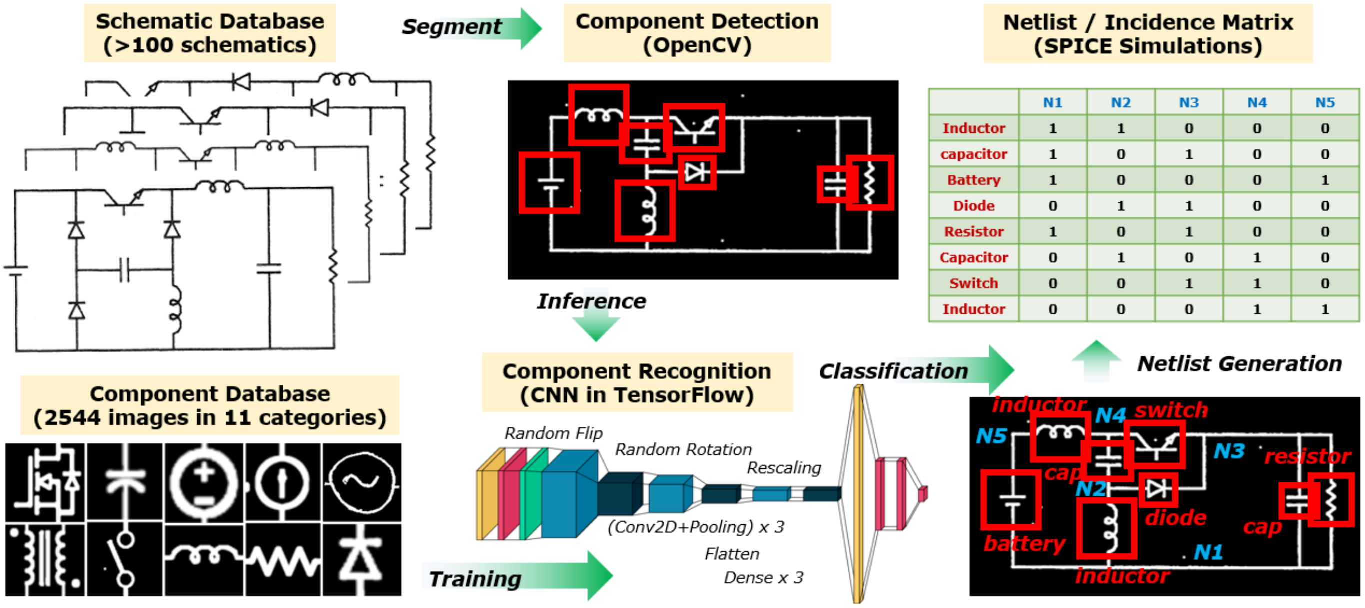


Fig. 6. The CircuitNet database encompasses 200 images representing various power electronics circuit topologies.

- **NetlistClassifier:** a computer program which classifies different power electronics schematic drawings and create labels such as "PWM", "isolated", etc.
- **NetlistSimulator:** The created netlist is SPICE compatible. The NetlistSimulator can simulate the netlist in SPICE (e.g., PySPICE in Python) to autonomously create new knowledge and label new data.

A. *ComponentNet and CircuitNet*

Figures 5 and 6 illustrate the principles of ComponentNet and CircuitNet. ComponentNet contains 2,544 hand-collected component images in 11 categories, including "ac-src", "battery", "cap", "curr-src", "diode", "inductor", "resistor", "swi-ideal", "swi-real", "volt-src", and "xformer". Each image is a 64×64 .PNG file with about 6 KB of size. CircuiNet contains 200 hand-collected circuit images with hand-labeled markers


Schematic Database (>100 schematics)
Segment
Component Detection (OpenCV)
Netlist / Incidence Matrix (SPICE Simulations)
Inference
Component Recognition (CNN in TensorFlow)
Classification
Netlist Generation
Component Database (2544 images in 11 categories)
Random Flip
Random Rotation
Rescaling
(Conv2D+Pooling) x 3
Flatten
Dense x 3
Training
inductor
N4
switch
N5
N3
resistor
cap
N2
battery
diode
cap
N1
inductor

	N1	N2	N3	N4	N5
Inductor	1	1	0	0	0
capacitor	1	0	1	0	0
Battery	1	0	0	0	1
Diode	0	1	1	0	0
Resistor	1	0	1	0	0
Capacitor	0	1	0	1	0
Switch	0	0	1	1	0
Inductor	0	0	0	1	1

Fig. 7. Key principles of the NetlistMaker tool. Initially, the 200 schematics stored in the schematic database undergo segmentation for component detection, utilizing OpenCV. Following segmentation, a CNN is trained using the component database to classify the detected components within the segmented schematics. Once classified, the components, along with network information, are transformed into an incidence matrix and represented as a netlist.

such as “PWM”, “non-PWM”, “isolated”, “non-isolated”, “inductive”, “capacitive”, “bi-directional” and so on. The image dimension pixels (width or height) range from 100 to more than 1000. Each image is in the size of about 15 KB. The image sources for the components and circuits include open-source databases, public images, textbooks, scientific publications, presentations, and technical application notes [13]–[15]. The ComponentNet is used to train a model which can recognize components in a schematic drawing. The CircuitNet is used to train a model which can convert schematic drawings into netlist and then perform classification or simulation.

B. NetlistMaker

Figure 7 illustrates the underlying principles of NetlistMaker, a fully automated image recognition tool designed to convert schematic drawings into netlists. Apart from employing a suite of standard image processing techniques like sharpening, color inverting, object detection, scaling, and normalization, NetlistMaker’s core comprises a convolutional neural network (CNN) tailored for component classification. This CNN architecture is specifically crafted and trained for power electronics. It features: 1) an image pre-processing layer for data augmentation, which randomly rotates, flips, and rescales component images; 2) three sets of 2D convolution and pooling layers; 3) a flatten layer followed by three dense layers for layer aggregation and classification. The training images are formatted as binary (64×64) pixels, and the CNN kernel size is (3×3). The model encompasses 276,491 parameters and occupies 1.05 MB of space. Figure 8 presents the confusion matrix of the classification results across 11 categories, with an overall accuracy of approximately 90%. Notably, the performance varies across different component models. Enhancements in component detection accuracy can be achieved through improved data, refined models, and optimized training processes.

TABLE I
CNN Architecture of the NetlistMaker

Layer (type)	Output Shape	Param #
Random Flip	(64, 64, 1)	0
Random Rotation	(64, 64, 1)	0
Rescaling	(64, 64, 1)	0
Conv 2D	(61, 61, 64)	1088
MaxPooling 2D	(30, 30, 64)	0
Conv 2D	(26, 26, 64)	102464
MaxPooling 2D	(13, 13, 64)	0
Conv 2D	(9, 9, 64)	102464
MaxPooling 2D	(4, 4, 64)	0
Flatten	1024	0
Dense	64	65600
Dense	64	4160
Dense	11	715

After detecting and labeling each component, the NetlistMaker then identifies how these components are connected with each other and create an incidence matrix. Each row of the incidence matrix represents a component in the schematic. Each column of the incidence matrix represents a wire node in the schematic. If one component is connected to a node (overlaps detected in the schematic), the element located at the corresponding row and column is sequentially marked as integer numbers “1”, “2”, “3”, etc. Different integer numbers indicate different ports of the same component. All other

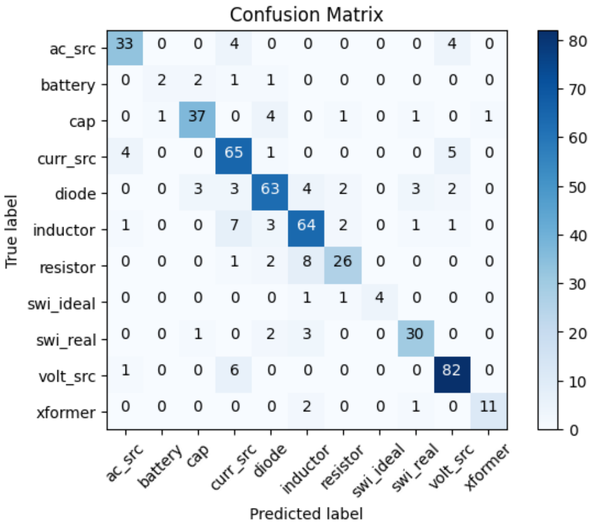


Fig. 8. The confusion matrix for classifying the 11 categories of components revealed that the model achieved satisfactory performance for most categories. It exhibited poor performance specifically for the "battery" and the "swi-ideal" categories, indicating a need for further refinement and improvement.

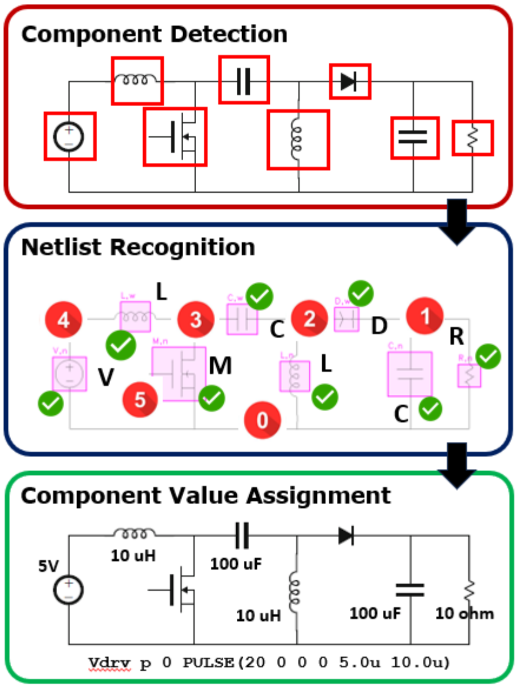


Fig. 9. The NetlistMaker processes an example SEPIC converter schematic drawing with: (1) component detection; (2) netlist recognition; and (3) component value assignment. The component values are randomly selected.

elements are marked as "0". The incidence matrix is a unique mathematical representation of the detected schematic, and can be used for SPICE simulation and topology classifications.

Figure 9 illustrates the key operation steps of NetlistMaker when processing a SEPIC converter. First, the components are detected with typical computer vision tools; Second, the components are recognized by the CNN, and the wires and connections are identified by image processing tools (such as OpenCV) through overlap detection; (3) each components are assigned with specific component values. In this particular example, the incidence matrix of this SEPIC converter is:

$$\left[\begin{array}{c|cccccc} & N_0 & N_1 & N_2 & N_3 & N_4 & N_5 \\ \mathbf{R} & 2 & 1 & 0 & 0 & 0 & 0 \\ \mathbf{C} & 2 & 1 & 0 & 0 & 0 & 0 \\ \mathbf{V} & 2 & 0 & 0 & 0 & 1 & 0 \\ \mathbf{L} & 2 & 0 & 1 & 0 & 0 & 0 \\ \mathbf{M} & 3 & 0 & 0 & 1 & 0 & 2 \\ \mathbf{L} & 0 & 0 & 0 & 2 & 1 & 0 \\ \mathbf{D} & 0 & 2 & 1 & 0 & 0 & 0 \\ \mathbf{C} & 0 & 0 & 2 & 1 & 0 & 0 \end{array}\right]. \tag{1}$$

Here the six columns – $\{N_0, N_1, N_2, N_3, N_4, N_5\}$ – represent the six nodes in the schematic, and the eight rows – $\{R, C, V, L, M, L, D, C\}$ – represent the eight components in the schematic. The NetlistMaker made a perfect schematic recognition in this example with all components and wire connections correctly identified. The SPICE netlist is:

```
* Netlist for sepic.net
* Sources:
V1 4 0 5                * voltage source
* Components:
R1 1 0 10               * load resistor
C1 1 0 10u              * output capacitor
L1 2 0 1u               * output inductor
M1 3 p1 0 0 mosfet      * main switch
L2 4 3 10u              * source inductor
D1 2 1 diode            * output diode
C2 3 2 10u              * blocking capacitor
* Drivers:
Vdrv1 p1 0 PULSE(20 0 0 0 0 5.0u 10.0u)
* Models:
.model mosfet NMOS(Kp=60 Vto=4.5)    * switch model
.model diode D                       * diode model
.tran 10m                            * simulation mode
.end
```

Figures 10 shows the component detection and recognition results of the 12 example topologies listed in Fig. 2. With a SPICE netlist, an AGI model can automatically call a SPICE simulation platform to enhance the learning process. In PowerVision, the generated SPICE netlist is then fed into PyLTSpice[2] - a tool-chain of python utilities design to interact with LTSpice. It is mostly based on the SPICELib[3] package, automatically selecting LTSpice to perform all simulations. Figure 11 shows an example simulation results from PyLTSpice for this SEPIC converter during a startup transient.

C. NetlistClassifier

We evaluate PowerVision's capability in classifying different circuit topologies. Human experts classify different circuit schematics by identifying the critical components and patterns in how they are connected to each other. An incidence matrix uniquely represents a circuit netlist and can be used as a key identifier. In NetlistClassifier, a netlist incidence matrix is first converted into a 2-D .PNG image whose element values are coded to represent different components, e.g., a "capacitor" row of the incidence matrix will be represented by a deeper color in a gray-scale image, and an "inductor" row of the

[2] PyLTSpice: https://pypi.org/project/PyLTSpice/

[3] SPICELib: https://github.com/nunobrum/spicelib

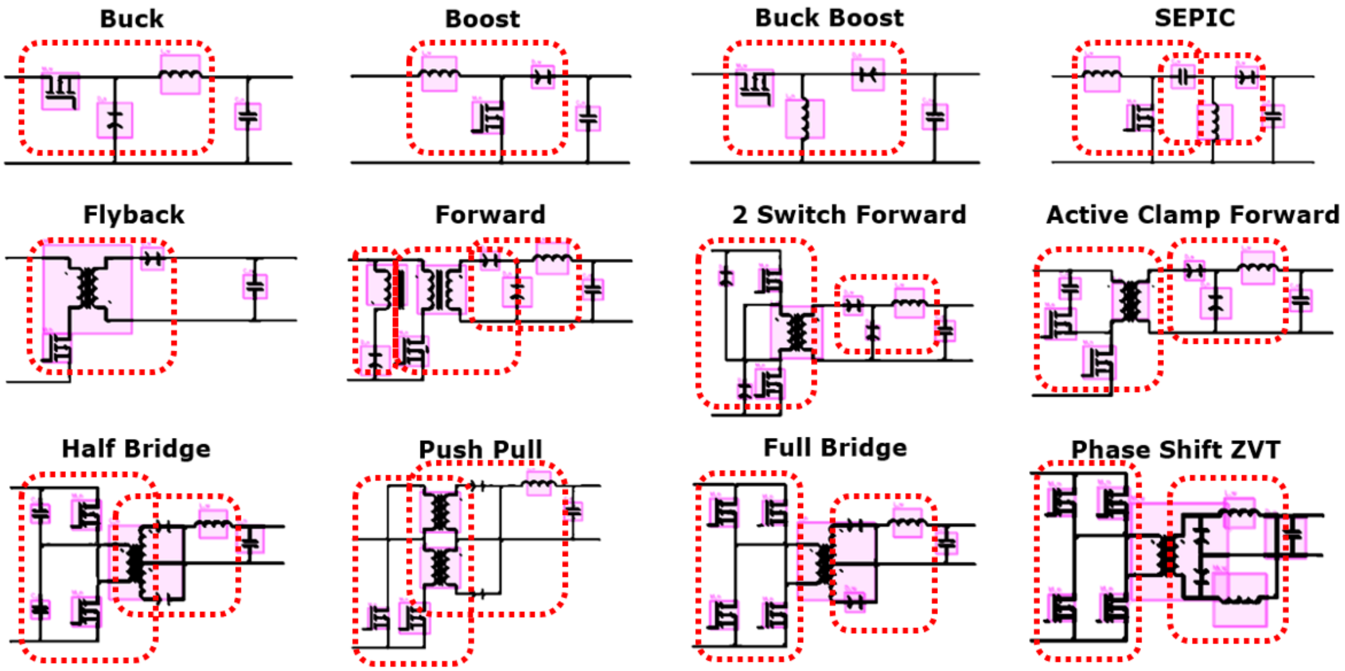


Fig. 10. Component detection and recognition results of the 12 example topologies listed in Fig. 2, with key circuit patterns highlighted.

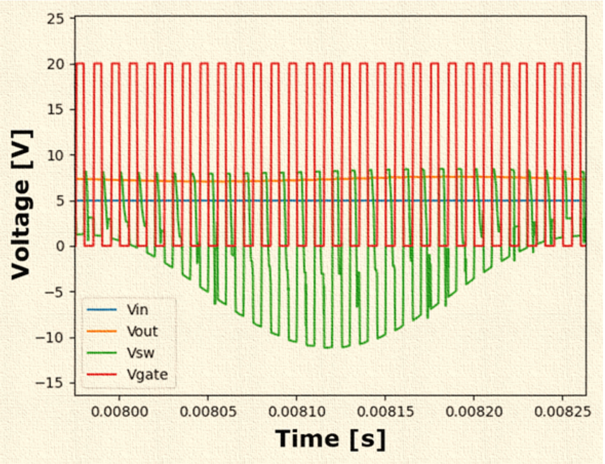


Fig. 11. PyLTspice simulation as a part of the PowerVision platform. The voltage waveforms of multiple switching nodes are shown.

incidence matrix is represented by a lighter color in a gray-scale image. In this way, the incidence matrix classification problem is converted into an image classification problem which can be solved by various computer vision tools.

Figure 12 explains the correlation between the patterns in the circuit schematic and the patterns in a color-coded incidence matrix. Human eyes recognize the patterns in the circuit schematic and infer the basic circuit behavior (e.g., a half-bridge switching cell usually comprises two switches and one inductor connected to one joint node). State-of-the-art machine learning algorithms (such as a Convolutional Neural Networks [16], or Transformers [17]) have similar “attention” mechanisms to recognize unique patterns in the incidence matrix, opening the opportunity to implement AGI models which can correlate circuit schematics with circuit functions.

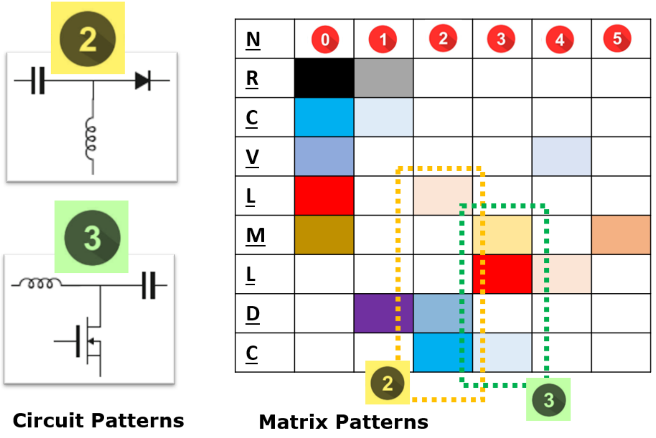


Fig. 12. The correlation between patterns in the circuit schematic and patterns in the incidence matrix. Human eyes rely on recognizing circuit patterns to infer circuit functions and behaviors. Machine intelligence rely on patterns in the incidence matrix to build connections with circuit functions.

Figure 13 illustrates a few example incidence matrices represented as 2-D gray-scale images, which can be processed as tensors for image recognition. Each row represents a component. Each column represents a node in the schematic. The non-black pixels represent non-zero elements in the incidence matrix. The component types are coded in the pixel darkness.

Table II lists the structure of the CNN of the Netlist-Classifier. The 200 schematics in the CircuitNet were all converted into 2-D images, then hand-labeled as “PWM”

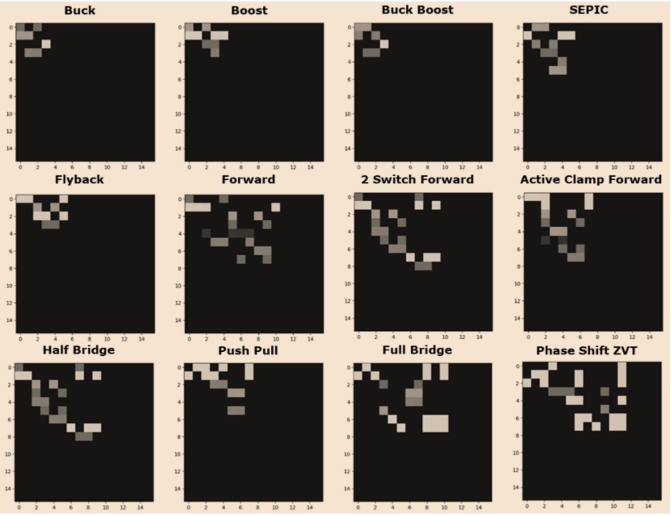


Fig. 13. 2-D gray-scale "fingerprint" images representing the incidence matrices of the 12 example topologies listed in Fig. 2. The size of these 2-D images are much smaller than the original schematic drawings.

TABLE II
CNN Architecture of the NetlistClassifier

Layer (type)	Output Shape	Param #
Conv 2D	(30, 30, 8)	80
MaxPooling 2D	(15, 15, 8)	0
Conv 2D	(13, 13, 8)	584
MaxPooling 2D	(6, 6, 8)	0
Flatten	288	0
Dense	8	2312
Dense	2	18

or "non-PWM", "isolated" or "non-isolated" converters. In each experiment, 160 schematics were used for training the NestlistClassifier model, and 40 schematics were used for testing. The confusion matrix for classifying the "PWM" and "isolated" converters are listed in Fig. 14. Without extensive training or model optimization, the accuracy for "PWM" vs. "non-PWM" classification was 70%. The accuracy for the "isolated" vs. "non-isolated" classification was 62.5%. Clearly, the PowerVision model we developed in this paper will not pass the power electronics Turing test.

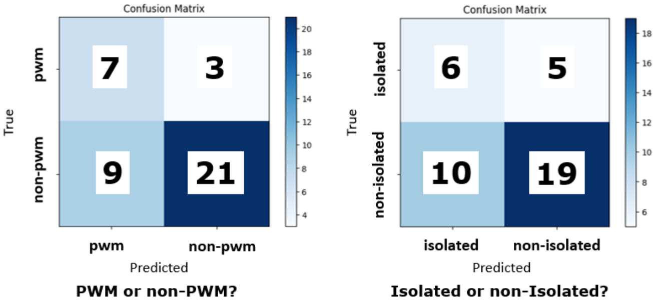


Fig. 14. Confusion matrix for classifying "PWM" and "isolated" converters. The accuracy for "PWM" vs. "non-PWM" classification was 70%. The accuracy for the "isolated" vs. "non-isolated" classification was 62.5%.

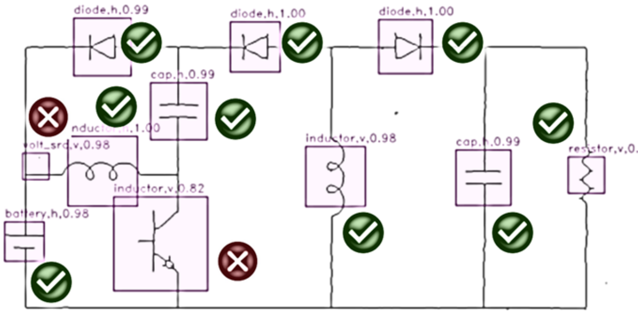


Fig. 15. Example component detection and classification results when reading an example circuit. It correctly detected the three diodes, two capacitors, two inductors, one battery, and one resistor, and the series and parallel relationships among them, and created a netlist. It mistakenly classified a transistor as an inductor, and mistakenly detect a wire-crossing as a voltage source which does not exist in the circuit. Potential ways to address these mistakes include (1) enlarging the database and improve the data quality; (2) utilizing better computer vision tools; and (3) developing better neural networks.

IV. Challenges and Opportunities

PowerVision's capabilities in component detection and topology classification are still far behind that of an average human learner. The inaccuracies in the PowerVision framework may stem from: (1) errors in component detection and netlist creation; (2) errors during the training and testing phases of classification; (3) errors in human labeling of components and schematics. These errors tend to propagate and magnify, limiting the overall end-to-end prediction accuracy.

An illustration of component detection and classification errors is provided in Fig. 15. Figure 16 shows a wide range of different symbols used for representing power transformers. PowerVision cannot differentiate these symbols, and cannot identify correct netlist if these symbols present in the schematics. Although the NetlistMaker generally performs well with over 90% accuracy, errors still occur, potentially influencing subsequent simulations or classifications. Other remaining challenges preventing PowerVision from rapidly learning from a massive amount of human-accessible data include:

- **Understanding semiconductor devices and magnetic components.** PowerVision cannot differentiate semiconductor devices and magnetic components drawn in different ways, and do not understand the principles used for designing them (e.g., turns ratios, lumped models, etc.).
- **Distinguishing circuits, text, markers, and labels.** Humans interpret schematics by integrating graphical netlist data with text positioned near graphic components. Over time, humans naturally learn to discern various formats of information (e.g., boxes, dashed lines, arrows, color highlights). Presently, PowerVision lacks the ability to independently interpret different types of drawing data.
- **Identifying and categorizing overlapping components.** Human excels at distinguishing and isolating close or even overlapping components. However, PowerVision currently lacks this capability.

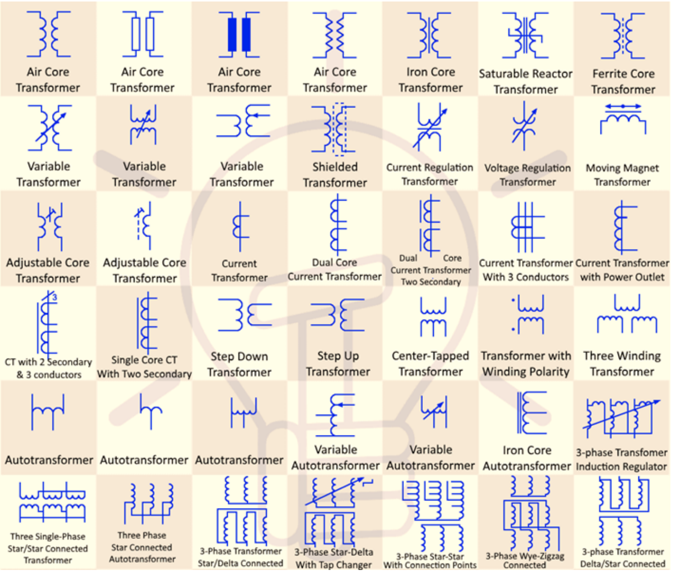

Air Core Transformer
Air Core Transformer
Air Core Transformer
Air Core Transformer
Iron Core Transformer
Saturable Reactor Transformer
Ferrite Core Transformer
Variable Transformer
Variable Transformer
Variable Transformer
Shielded Transformer
Current Regulation Transformer
Voltage Regulation Transformer
Moving Magnet Transformer
Adjustable Core Transformer
Adjustable Core Transformer
Current Transformer
Dual Core Current Transformer
Dual Core Current Transformer Two Secondary
Current Transformer With 3 Conductors
Current Transformer with Power Outlet
CT with 2 Secondary & 3 conductors
Single Core CT With Two Secondary
Step Down Transformer
Step Up Transformer
Center-Tapped Transformer
Transformer with Winding Polarity
Three Winding Transformer
Autotransformer
Autotransformer
Autotransformer
Variable Autotransformer
Variable Autotransformer
Iron Core Autotransformer
3-phase Transformer Induction Regulator
Three Single-Phase Star/Star Connected Transformer
Three Phase Star Connected Autotransformer
3-Phase Transformer Star/Delta Connected
3-Phase Star-Delta With Tap Changer
3-Phase Star-Star With Connection Points
3-Phase Wye-Zigzag Connected
3-phase Transformer Delta/Star Connected

Fig. 16. A wide range of different power transformer models (Available: https://www.electricaltechnology.org/2019/09/transformer-symbols.html).

- **Interpreting wire connections.** Humans possess the ability to recognize and understand concepts like "cross-wires" and "junctions" within schematic drawings. However, PowerVision currently lacks this capability.
- **Automated error correction.** Human readers often possess the capacity to comprehend a schematic by focusing on high-level information and overlooking minor errors. Flawless understanding on the circuit is not needed. However, PowerVision currently lacks this ability.

Domain-specific AGI tools like PowerVision will continue to benefit from advancements in general-purpose AGI. Addressing these limitations can be achieved through: (1) improved dataset size and quality; (2) forthcoming developments in computer vision and multi-modal learning; (3) refined model architecture and training strategies; (4) deep understandings about errors and approximations.

Training a comprehensive AGI model to comprehend power electronics falls beyond the scope of this paper. However, leveraging the PowerVision tool enables the swift conversion of numerous power electronics schematics into netlists, thereby establishing a sizable multi-domain database primed for training. We've devised a software framework to automate this process entirely. Utilizing a PDF segmentation tool (PDFSegmenter[4]), we automatically extract images and text from a vast array of PDF documents. Schematic images, their corresponding netlists (including incident matrices), and descriptive texts are then paired and stored within the database. Ultimately, this entire procedure can be automated and seamlessly integrated with a general-purpose AGI model.

V. Conclusion

This paper introduces PowerVision as a research framework for investigating the power electronics Turing test – a domain-specific method for assessing the proficiency of AGI models' capability of understanding power electronics. PowerVision facilitates automatic conversion of schematic diagrams from power electronics literature into netlists, enabling basic tasks such as SPICE simulations and topology classification. These tools have the potential to significantly expedite the training of general-purpose AGIs with domain-specific knowledge, and enabling them to hierarchically process information and provide useful guidelines in power electronics design.

[4] PDFSegmenter: https://pypi.org/project/PDFSegmenter/

References

[1] Y. LeCun, Y. Bengio, and G. Hinton, "Deep learning," *Nature*, vol. 521, no. 7553, pp. 436–444, May 2015.

[2] G. Linán-Cembrano, N. Lourenço, N. Horta, and J. M. de la Rosa, "Design automation of analog and mixed-signal circuits using neural networks—a tutorial brief," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 71, no. 3, pp. 1677–1682, 2024.

[3] J. Yang, K. Qiao, S. Shi, B. Song, J. Chen, and B. Yan, "Aem-pcb reverser: Circuit schematic generation in pcb reverse engineering using reinforcement learning based on aesthetic evaluation metric," *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, vol. 43, no. 5, pp. 1608–1612, 2024.

[4] H. Wang, K. Wang, J. Yang, L. Shen, N. Sun, H.-S. Lee, and S. Han, "Gcn-rl circuit designer: Transferable transistor sizing with graph neural networks and reinforcement learning," in *2020 57th ACM/IEEE Design Automation Conference (DAC)*, 2020, pp. 1–6.

[5] J. Deng, W. Dong, R. Socher, L.-J. Li, K. Li, and L. Fei-Fei, "Imagenet: A large-scale hierarchical image database," in *2009 IEEE Conference on Computer Vision and Pattern Recognition*, 2009, pp. 248–255.

[6] H. Li *et al.*, "Magnet: An open-source database for data-driven magnetic core loss modeling," in *2022 IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2022, pp. 588–595.

[7] A. M. TURING, "I.—COMPUTING MACHINERY AND INTELLIGENCE," *Mind*, vol. LIX, no. 236, pp. 433–460, 10 1950. [Online]. Available: https://doi.org/10.1093/mind/LIX.236.433

[8] OpenAI, "Chatgpt," https://www.openai.com/gpt-3, 2022.

[9] D. Maksimovic and S. Cuk, "A general approach to synthesis and analysis of quasi-resonant converters," *IEEE Transactions on Power Electronics*, vol. 6, no. 1, pp. 127–140, Jan 1991.

[10] B. Bohara and H. S. Krishnamoorthy, "Computer vision based framework for power converter identification and analysis," in *2022 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, 2022, pp. 1–6.

[11] A. E. Sertdemir *et al.*, "From image to simulation: An ann-based automatic circuit netlist generator (img2sim)," in *International Conf. on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD)*, 2022, pp. 1–4.

[12] H. B. Gurbuz *et al.*, "Img2sim-v2: A cad tool for user-independent simulation of circuits in image format," in *International Conf. on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD)*, 2023, pp. 1–4.

[13] J. G. Kassakian *et al.*, *Principles of Power Electronics*, 2nd ed. Cambridge University Press, 2023.

[14] R. W. Erickson and D. Maksimovic, *Fundamentals of Power Electronics*, 3rd ed. Springer Nature Switzerland AG, 2020.

[15] P. Krein, *Elements of Power Electronics*, 2nd ed. Oxford University Press, 2014.

[16] A. Krizhevsky, I. Sutskever, and G. E. Hinton, "Imagenet classification with deep convolutional neural networks," *Commun. ACM*, vol. 60, no. 6, p. 84–90, may 2017.

[17] A. Vaswani, N. Shazeer, N. Parmar, J. Uszkoreit, L. Jones, A. N. Gomez, L. Kaiser, and I. Polosukhin, "Attention is all you need," in *Advances in Neural Information Processing Systems*, vol. 30, 2017.