Visualizing a Classic CPU in Action: The 6502

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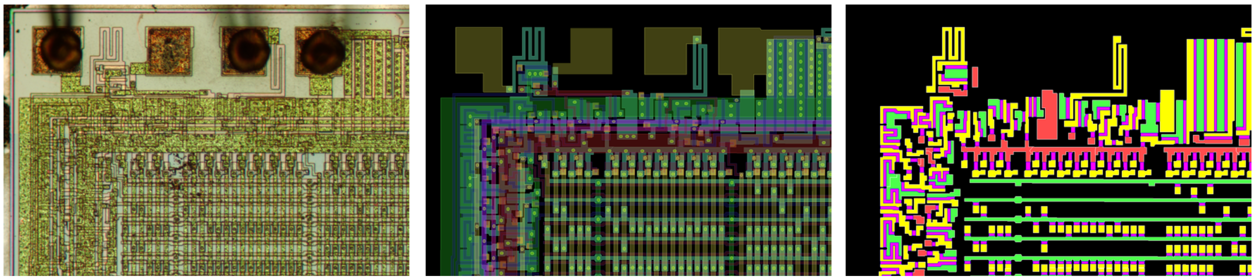

Figure 1: *A section of the 6502 showing, from left to right, (1) a chip die photograph from which a polygon representation was derived, (2) all polygons corresponding to physical chip layers (3) polygons reduced to substrate regions split by transistors, where green and red indicate substrate connected to ground and supply, and yellow indicates substrate switched between ground and supply by transistors.*

Abstract

We present a real-time interactive simulation and visualization of the classic 6502 microprocessor as it executes instructions and processes data. A polygon model of each physical layer of the 6502 was created and transformed into a network of wires and transistors suitable for our logic simulator. Tools were developed to provide constant visual feedback of the work-in-progress, which yielded a correct model immediately after finishing the vectorization. This avoided the errors and long debug phase encountered in similar projects.

Keywords: visualization, microprocessor, MOS 6502, simulation, computer history, integrated circuit

1 Introduction and Motivation

Most users have a basic understanding of computer hardware, but there is a significant barrier to discovering more about how that hardware operates. Chip features are microscopic, embedded in tough opaque material, and easily destroyed by attempts to reveal them. Very few people have seen a transistor, much less a network of transistors put together to accomplish some goal. Even when photographs and diagrams of circuits are available, the static images reveal next to nothing about how circuits operate. In creating an interactive visual representation of a physical chip and its logic state, we reveal every detail of its operation and can easily explain the function of its various parts.

Unlike today's microprocessors, the 6502 was laid out by hand on drafting boards. A digital representation of the chip was not available. Its features were not routed or optimized by computer, which makes them an attractive target for study. Though knowledge of its instruction set is widespread, the physical components used to execute that set were not known; components which live on in today's processor designs. With our logic simulation derived directly from physical chip features, it is now possible for an educated laymen to study a microprocessor in full detail. Our project enables the preservation, study, and appreciation of this classic CPU and the early Apple and Atari computers in which it was used.

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2 Our Approach

High resolution photomicrographs of the surface of a 6502 chip were shot and assembled into a single image using a custom GPU-accelerated application driven by Python script. The chip was then stripped down to its substrate features, re-photographed, and the substrate images were assembled into a second full layer aligned with the surface image. From these two images, we derived polygonal representations of each physical layer of the chip, including conductive substrate regions, polysilicon gate wires, buried contact areas, vias, and the topmost metal layer.

Connectivity between these layers is described by simple rules which, in turn, allow the creation of a full chip netlist and logic simulation by simple geometric intersection of various layers. Unlike previous work [McNerney 2006] in which logical models were derived from tabulated or translated data, prone to errors, and required protracted and difficult debugging, our approach of using nothing but an image-based representation produced an accurate netlist immediatley after the polygonization was complete. We encountered only 8 errors in forming our representation of over 20,000 components, and each of these errors was spotted and corrected as the vectorization proceeded. We believe this approach is best suited to the preservation and study of other early microprocessors.

3 Conclusion

Attendees should come away with a new, intuitive, visual understanding of microprocessors and an appreciation for the design and elegance of a chip that played a major role in the home computer revolution. The form and function of chip registers, the decoding and execution of program instructions, and the challenges of processor design will be explained on a level that both non-technical users and advanced engineers can appreciate.

References

MCNERNEY, T., 2006. Intel 4004 project. website www.4004.com.