time, there is never any ambiguity due to slight timing differences. The first eight elements of the code are as follows:

Binary Code	Gray Code
000	000
001	001
010	011
011	010
100	110
101	111
110	101
111	100

Design a circuit that converts from binary to Gray code.

B.12 Design a 5 × 32 decoder using four 3 × 8 decoders (with enable inputs) and one 2 × 4 decoder.

B.13 Implement the full adder of Figure B.22 with just five gates. (*Hint:* Some of the gates are XOR gates.)

B.14 Consider Figure B.22. Assume that each gate produces a delay of 10 ns. Thus, the sum output is valid after 30 ns and the carry output after 0 ns. What is the total add time for a 32-bit adder

a. Implemented without carry lookahead, as in Figure B.21?

b. Implemented with carry lookahead and using 8-bit adders, as in Figure B.23?

APPENDIX C

PROJECTS FOR TEACHING COMPUTER ORGANIZATION AND ARCHITECTURE

C.1 **Research Projects**

C.2 **Simulation Projects**

SimpleScalar
SMPCache

C.3 **Reading/Report Assignments**

Many instructors believe that research or implementation projects are crucial to the clear understanding of the concepts of computer organization and architecture. Without projects, it may be difficult for students to grasp some of the basic concepts and interactions among components. Projects reinforce the concepts introduced in the book, give students a greater appreciation of the inner workings of a processor, and can motivate students and give them confidence that they have mastered the material.

In this text, I have tried to present the concepts of computer organization and architecture as clearly as possible and have provided numerous homework problems to reinforce those concepts. Many instructors will wish to supplement this material with projects. This appendix provides some guidance in that regard and describes support material available in the instructor's manual. The support material covers three types of projects:

- Research projects
- Simulation projects
- Reading/report assignments

C.1 RESEARCH PROJECTS

An effective way of reinforcing basic concepts from the course and for teaching students research skills is to assign a research project. Such a project could involve a literature search as well as a Web search of vendor products, research lab activities, and standardization efforts. Projects could be assigned to teams or, for smaller projects, to individuals. In any case, it is best to require some sort of project proposal early in the term, giving the instructor time to evaluate the proposal for appropriate topic and appropriate level of effort. Student handouts for research projects should include:

- A format for the proposal
- A format for the final report
- A schedule with intermediate and final deadlines
- A list of possible project topics

The students can select one of the listed topics or devise their own comparable project. The instructor's manual includes a suggested format for the proposal and final report as well as a list of possible research topics.

C.2 SIMULATION PROJECTS

An excellent way to obtain a grasp of the internal operation of a processor and to study and appreciate some of the design trade-offs and performance implications is by simulating key elements of the processor. Two useful tools that are useful for this purpose are SimpleScalar and SMPCache.

Compared with actual hardware implementation, simulation provides two advantages for both research and educational use:

- With simulation, it is easy to modify various elements of an organization, to vary the performance characteristics of various components, and then to analyze the effects of such modifications.
- Simulation provides for detailed performance statistics collection, which can be used to understand performance trade-offs.

SimpleScalar

SimpleScalar [BURG97, MANJ01a, MANJ01b] is a set of tools that can be used to simulate real programs on a range of modern processors and systems. The tool set includes compiler, assembler, linker, and simulation and visualization tools. SimpleScalar provides processor simulators that range from an extremely fast functional simulator to a detailed out-of-order issue, superscalar processor simulator that supports nonblocking caches and speculative execution. The instruction set architecture and organizational parameters may be modified to create a variety of experiments.

The instructor's manual for this book includes a concise introduction to SimpleScalar for students, with instructions on how to load and get started with SimpleScalar. The manual also includes some suggested project assignments.

SimpleScalar is a portable software package the runs on most UNIX platforms. The SimpleScalar software can be downloaded from the SimpleScalar Web site. It is available at no cost for noncommercial use.

SMPCache

SMPCache is a trace-driven simulator for the analysis and teaching of cache memory systems on symmetric multiprocessors [RODR01]. The simulation is based on a model built according to the architectural basic principles of these systems. The simulator has a full graphic and friendly interface. Some of the parameters that they can be studied with the simulator are: program locality; influence of the number of processors, cache coherence protocols, schemes for bus arbitration, mapping, replacement policies, cache size (blocks in cache), number of cache sets (for set associative caches), number of words by block (memory block size).

The instructor's manual for this book includes a concise introduction to SMPCache for students, with instructions on how to load and get started with SMPCache. The manual also includes some suggested project assignments.

SMPCache is a portable software package the runs on PC systems with Windows. The SMPCache software can be downloaded from the SMPCache Web site. It is available at no cost for noncommercial use.

C.3 READING/REPORT ASSIGNMENTS

Another excellent way to reinforce concepts from the course and to give students research experience is to assign papers from the literature to be read and analyzed. The instructor's Web site includes a suggested list of papers to be assigned, organized by chapter. All of the papers are readily available either via the Internet or in any good college technical library. The instructor's Web site also includes a suggested assignment wording.