Future of Applications

CRPC Book Chapter, Extended Outline

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Introduction (1 page)

Today, computers have taken over some very small fraction of our decision-making responsibility and assist us in more – anti-lock brakes, whether to wear a raincoat or sun block to work, information access on the Web, and fly-by-wire in aircraft are some common examples. Even so, the scope of the decisions in which computer simulation plays a dominant role remains fairly limited.

However, as society's infrastructures have grown increasingly complex, interdependent and fragile, the need for better informed, more accurate and timely decisions has grown corresponding critical. The plight in which we find ourselves is succinctly stated in the following excerpt from The Political Limits to Forecasting,

> " … it is clear that decision aptitudes are sharply challenged. The range of alternatives is greater. The underlying technical facts are more difficult to comprehend because of their sophistication and specialised jargon, and the consequences of error are more lethal and irreversible. Decision-makers are perplexed by new levels of complexity and hyper-interdependence in our society, accompanied by uncertainty, a heightened pace of social change, and discontinuities in utility of past experience."

The last phrase is the most telling – decisions based on rules-of-thumb responses honed over years of trial and error are becoming less and less likely to yield acceptable solutions. The ability to reliably project alternative courses of action (e.g. global climate scenarios, war fighting strategies, electrical power deregulation policies) into the future in order to assess the impacts and consequences of each course of action may be a key to our prosperity, even survival, in the next millennium.

The problems we face affect lives, security, and well-being at, potentially, every level of society. Further, the application of computing technology to the solution of these problems demand predictive modeling and simulation at a fidelity, scale, and tempo that are far beyond our current technological ability.

Report Card from '90s (6 pages)

Astrophysics.

The ability to detail the consequences of various astrophysical theories has sharpened the focus of this field tremendously. We will review some of the specific accomplishment.

Weather

The ability to predict severe weather, e.g. hurricanes and tornadoes, has made considerable progress over the last decade. We will review the work of the NSF S&T Center for Analysis and Prediction of Storms (CAPS) and National Hurricane Center.

Climate

The design and development of a new generation of global ocean models has brought ocean simulations to the point where the primary dynamics are being accurately reproduced. This new generation of models was catalyzed and supported by MPPs.

Design of Boeing 777

It is often said that the Boeing 777 was designed by computer. Actually, computer modeling played a major role in physical layout of the aircraft (solid-body modeling), but did not replace test and evaluation of the airframe, except in wing bend-to-fracture tests.

Seismic Processing

Seismic processing is one of the areas in which it has made sense to employ MPPs, because a ROI can be attained within the short life time to a particular piece of hardware. We will review the progress of using high-end computing to analyze seismic data.

Transims

The EPA mandates detailed environmental studies prior to any significant change in metropolitan transportation systems. TRANSIMS models traffic flow by representing all of the traffic infrastructure (e.g. streets, freeways, lights, stop signs), developing a statistically correct route plan for the area's population, and then simulating the movement of each car, second by second.

Predicting the future. (10 pages)

The capacity of high-end computers has increased 10 orders of magnitude since 1956, assuming that ASCI and Stockpile Stewardship reach their goal of 100 TeraFlops at Los Alamos in 2004. If we examine the improvements made in other seminal tools of discovery nothing approaches the gains that high-performance computing has made.

Stockpile Stewardship

Stockpile Stewardship is taking the lead in using computer models to extrapolate the properties and behavior of systems, in this case the safety and reliability of the U.S. nuclear arsenal, that cannot be adequately examined by experiment

Natural hazards

Over the next decade, simulations of natural hazards – hurricanes, severe thunderstorms, wildfire, floods, perhaps even earthquakes -- will evolve as one of the primary tools for predicting the course of such events and using this knowledge to mitigate their impact on society.

Critical infrastructure

Fundamental human support systems, -- electricity, transportation, communication, health care – are becoming increasingly complex and interdependent. Planning and training in this area, ranging from management of short-term crisis situations (e.g. terrorist activities) to effective long-term investment strategies (e.g. deregulation of electric power generation), will rely more and more upon coupled simulations of physical infrastructure and human-dominated forces thereupon.

Bioscience and biotechnology

The next decade will belong to bioscience and to information science. At this interface we will find the most interesting and rapidly changing interplay.

Information Management

Instant access to existing information has increased dramatically over the last ten years. However, new data acquisition tools (e.g. EOS, SAR, sensor swarms) promise to increase the volume and frequency of scientific data to a flood. Effective management of this information - fusion, analysis, presentation, quality assurance – particularly in time-urgent situations will be a challenge for the next decade and beyond.

The Fundamental Challenges. (5 pages)

Quantification of uncertainty.

Trust is the single most important quality to policy and decision-makers. Therefore, verification, validation, quantification and presentation of uncertainty will be the key to providing useful tools based on computer predictions to decision-makers.

Computer science and applied mathematics.

Simulation of complex, time-critical, high-consequence events and scenarios will require algorithms and computer systems at a scale that does not yet exist. Effective use of these systems requires focus in the computer science and applied mathematics communities on issues associated with strategic computing.

Modeling human-dominated systems.

The social sciences, e.g. economics, psychology, population dynamics, must play a central role in any realistic simulations of national infrastructure or crisis situations. Underlying these simulations must a mathematically and statistically sound framework of individual and collective interactions.

Policy and decision-making.

In order to effectively embed modeling and simulation into decision-making we must understand the processes involved on a logical and psycho-logical basis.

Content-context translation.

Each decision-maker has a developed a particular style over many years of trial and error. Thus, order to be most effective, information content must be presented in the appropriate context and with a style compatible with the style of the individual decision-maker.