An Interactive Multimedia System for Fire Behavior Training

J.A. Hoskins*, W.D. Hoskins*, K.G. Hirsch**

*University of Manitoba
**Northern Forestry Centre

Abstract:
This paper discusses the development of a multimedia transfer technology system for the information contained in and required by the Canadian Forest Fire Behavior Prediction (FBP) System. The multimedia system consists of a diverse set of visual, numerical, and empirical models unified in their approach to simulating, explaining and elaborating the concepts and methodology of the FBP System. It is large (approximately 125 mb at the present time) and is sufficiently comprehensive that it can serve as a research tool, as well as an educational environment. This paper illustrates the complexity of the problem domain and some of the interactive and instructional dilemmas faced in the construction of this system. It also outlines some of the directions where further development is proceeding.

Introduction
Across Canada about 2.5 million hectares of forested area are burned by wildfire each year, incurring fire management costs of almost $250 million (CDN). In an effort to deal more effectively with the problem of forest fire management, a group of Forestry Canada researchers, collectively known as the Fire Danger Group, have developed the Canadian Forest Fire Behavior Prediction (FBP) System [1]. The FBP System is a complex system that uses fuel (i.e. live and dead vegetation), weather and topographic information to predict a variety of fire behavior characteristics such as the rate of fire spread, fire intensity, and the size and shape of a free burning wildfire. Effective use of the FBP System by fire managers requires not only familiarity with the model's inputs and outputs but also a thorough understanding of the underlying principles on which the system is based.

Traditionally fire researchers in Forestry Canada have participated in technology transfer and training activities that assist the dissemination and use of research results. This has meant going beyond the publication of technical papers to the development of workbooks and instructing at operational training courses. Recently it has become possible to further improve this process by constructing comprehensive, and potentially more effective, multimedia systems for fire behavior training.

The primary objectives of this research project were to examine the applicability of a multimedia approach to the problem of FBP System training, as well as to explore the development constraints and challenges in developing such a system. We believed that this particular problem domain, with its need for the presentation of complex visual and textual information, was ideally suited to a multimedia environment. Forest fuel information could, we felt, be most effectively described with reference to colored photographs; fire intensity and rate of spread could be presented very powerfully through the inclusion of carefully selected video footage; and the relationship between the inputs and outputs could be developed through the use of inter-linked and cross-referenced text, diagrams and equations. We were also particularly interested in exploring data animation techniques and special purpose calculation segments that would effectively explain the complex mathematical relationships inherent in the FBP System model. A secondary goal was to determine whether the multimedia system could be made comprehensive enough to be used as an operational interactive reference for fire researchers and fire fighters.

The purpose of this paper is to introduce the problem domain and to discuss the approach that we took in carrying out our research objectives. We present an example, which is intended to show some of the design considerations and give a flavour for the multimedia system that was developed. We also briefly discuss the ways in which this system has thus far been utilized.

Problem Domain and Approach
The FBP System
The FBP System is an empirical and theoretical system based on observations of fire behavior collected over two decades on experimental fires and wildfires [1]. At the heart of the FBP System is a complex mathematical model using in excess of eighty inter-related equations which relate fourteen input parameters to four primary and eleven secondary outputs (Figure 1) [1].

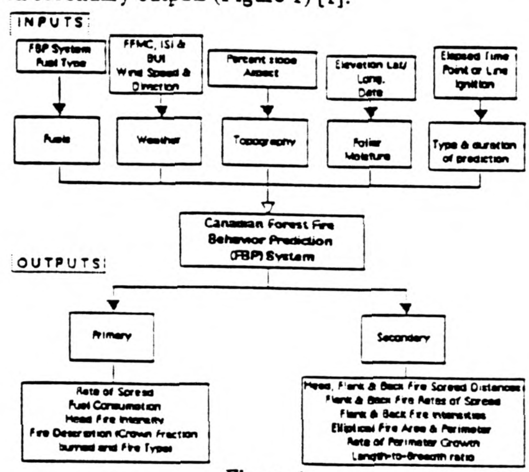

Figure 1
Structure of the FBP System

Inputs: The FBP System inputs can be broadly classified as fuels, weather, topography, foliar moisture content, and type and duration of prediction.

(1) Fuels: The FBP System has sixteen general fuel types which represent most of the major fuel types found in Canada (Table 1). A fuel type can be defined as an identifiable association of fuel elements of distinctive species, form, size, arrangement, and continuity that will cause a predictable rate of spread or difficulty of control under specified weather conditions.
(2) Weather: The FBP System uses the Fine Fuel Moisture Code (FFMC), the Initial Spread Index (ISI), and the Buildup Index (BUI) which are components of the Canadian Forest Fire Weather Index (FWI) System [2]. The FWI System provides numerical ratings of relative fire potential and has been used across Canada since the early 1970's. The FWI indexes are considered weather inputs because they are calculated directly from observations of temperature, relative humidity (RH), wind speed, and precipitation. The FBP System can also use detailed (e.g. hourly) observations or forecasts of wind speed and wind direction[3,4].

(3) Topography: Required inputs are percent slope and aspect (i.e. slope direction).
(4) Foliar Moisture Content: The percent foliar moisture content (FMC) is computed using the latitude (°N), longitude (°W), elevation (m) above mean sea level (MSL), and the date. The FMC influences calculations relating to crown fire involvement and is only computed for coniferous and mixedwood fuel types. It also modifies the crown fire rate of spread model in the (C-6) fuel type.
(5) Type and Duration of Prediction: The FBP System allows for two different types of fire behavior predictions (i.e. point or line ignition) depending on whether or not the fire has reached its equilibrium rate of spread.

Category	Fuel Type	
coniferous	C-1	Spruce/Lichen Woodland
	C-2	Boreal Spruce
	C-3	Mature Jack or Lodgepole Pine
	C-5	Red and White Pine
	C-6	Conifer Plantation
	C-7	Ponderosa Pine/Douglas-fir
deciduous	D-1	Leafless Aspen
mixedwood	M-1	Boreal Mixedwood - Leafless
	M-2	Boreal Mixedwood - Green
	M-3	Dead Balsam Fir/Mixedwood - Leafless
	M-4	Dead Balsam Fir/Mixedwood - Green
slash	S-1	Jack or Lodgepole Pine Slash
	S-2	Spruce/Balsam Slash
	S-3	Coastal Cedar/Hemlock/Douglas-fir Slash
open	O-1a	Matted Grass
	O-1b	Standing Grass

Table 1

Outputs: The FBP System has both primary and secondary outputs. The primary outputs relate directly to an equation, developed by Byram[5], that defines the concept of fire intensity. In the FBP System the rate of spread (m/min), fuel consumption (kg/m^2), and head fire intensity (kW/m) are predicted. The fourth primary output predicted by the FBP System, fire description, is defined by the degree of crown involvement or crown fraction burned (CFB). The eleven secondary outputs (Figure 1) are based on the assumption that a fire will grow in an elliptical shape if conditions remain constant and these outputs provide predictions of fire progression, fire shape, fire size and acceleration.

Development Process: In presenting a program of instruction on the FBP System, instructors are required to describe and explain the input parameters and output values, as well as the computational processes that relate the two. A special emphasis is placed on the interpretation of the output values and their operational application. In these courses, static examples which involve simple numerical calculations are presented. These are intended to address special areas where insight or subtlety, combined with some experience or practical knowledge, would be necessary.

To meet our practical objectives, the multimedia system was required to be attractive, highly interactive and non-sequential. To provide the level of completeness for which we were aiming, it was also necessary to include all equations and raw raw data used to construct the models, which in turn necessitated some form of data visualization [6].

In approaching the development of the multimedia system, the first two authors, who at the time had virtually no knowledge of forest fire behavior, participated in a one week FBP System training course given by the third author. We then proceeded to investigate the relationships between conceptual elements which had, of necessity, been presented in the course, and in the workshop materials, in a linear fashion. Supporting visual material was acquired from Forestry Canada and the Forest Technology School in Hinton, Albertaand was incorporated as required. In addition, we referenced the formal specification of the FBP System [1] and implemented the model within the developing system. This was intended to verify our own complete understanding of the mathematical processes in the FBP System, as well as to provide an environment in which users could experiment with their acquired knowledge of the relationships between inputs and outputs. This FBP System calculator, which was developed to be highly interactive, was maintained in the multimedia environment as a complete entity. Components of it were also incorporated into other sections where the opportunity to observe the impact of changing input values on predicted outputs provides considerable insight into the model. In attempting to explain some of the more complex mathematical relationships, we also provided novel interactive graphing capabilities, as described in the example. The development process itself was highly interactive and nonlinear, consisting of the construction of conceptual units, evaluation by the development team, refinement, other forms of input and additional refinement. A particular challenge was to ensure that we used the full capability of these media, rather than simply creating a software version of existing materials. This lead to lively discussion and a truly inter-disciplinary developmental approach with many ideas being brought forward, evaluated, modified and sometimes culled.

Implementation
This FBP System training package was developed for the Macintosh computer with Aldus SuperCard being used as the primary multimedia tool. The active elements were designed as 14 independent cross-linked stacks.This created a number of obvious advantages, the first being that none of the stacks is excessively large (the largest, just under a megabyte). The second advantage is that development of separate sections could proceed in parallel. The third advantage is that some of the stacks have functional utility as stand-alone segments.

Approximately 100 color photographs were scanned and edited, using Adobe PhotoShop, and stored as 8 bit pict files. The pict files, themselves, have not been made a part of the SuperCard stacks but are, instead, retrieved from disk when they are needed. Once again, this reduces the stack size, since each photograph takes approximately 750K of storage. It also allows for photographs to be easily replaced or updated, if necessary.

The entire computational FBP System was implemented in an interactive, self explaining cross-linked form. Some aspects of the training package are computationally intensive (e.g. FBP tutorial calculator) and, in order to maintain a highly interactive environment, it is necessary that this computation occur virtually instantaneously. For that reason, the computation was not carried out in Aldus' SuperCard but, rather, as external function commands written in Symantec's Think Pascal.

Video sequences of fires were captured using SuperMac's Video Spigot, edited using Adobe Premier, and linked to the stacks in the same way as the photographs. Apple's QuickTime and Black Mountain's Multimedia Externals are used to display the video sequences.

Example
For this system to be used by the fire management community it has to exceed or enhance currently available products or techniques used in training or research activities. Intermediate versions of this multimedia system have been shown to and used by operational forest fire management staff, managers, researchers, and educators. Response to and support of the program has, in general, been extremely positive indicating that this package does provide an innovative approach to fire behavior training. Discussion of all of the components of the package is beyond the scope of this paper; however, the following example is representative of the nature of the subject material, as well as the approach that has been taken.

This example illustrates the process of determining whether a fire burning in the Conifer Plantation (C-6) fuel type, under a given set of conditions, will be a surface fire or a more severe intermittent or continuous crown fire. It shows the complexity of the calculations required and the format in which this information is presented.

Figure 2 serves to identify the critical elements in the display. It shows the predicted values and outcomes for sample data. The illustrated input parameters are: CBH Crown Base Height (i.e. height from the ground to the base of the live tree crown); BUI Buildup Index; BE buildup effect; FMC foliar moisture content; FME foliar moisture effect, and FFMC Fine Fuel Moisture Code.

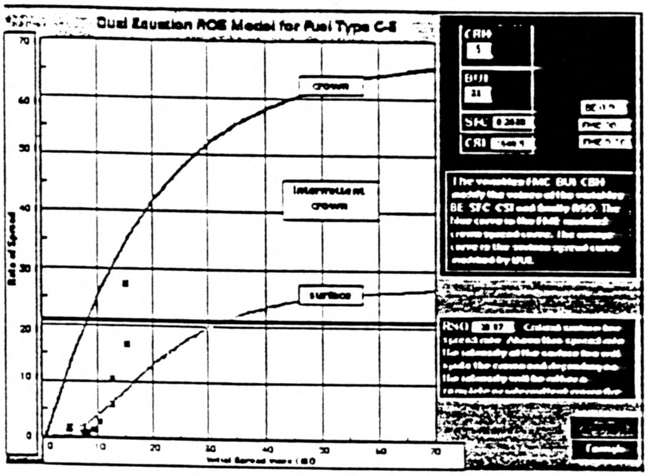

Figure 2
Rate of Spread for the Conifer Plantation (C-6) Fuel Type

The outputs are: SFC surface fuel consumption; CSI critical surface fire intensity for crowning; RSO critical surface fire rate of spread for crowning; CFB crown fraction burned, and the surface and crown fire rate of spread functions (lower and upper curves, respectively). The data points, marked with an x, show the actual measured values for fires in the FBP System database for the C-6 fuel type. The horizontal line is the critical value for rate of spread, above which a surface fire will theoretically generate sufficient heat to ignite some portion of the tree crowns. The amount by which the critical rate of spread is exceeded will determine the degree to which the crown fire is involved. To calculate the final rate of spread for the C-6 fuel type, a total of sixteen equations are required. These equations, and a very brief explanation, are as follows. (A description of abbreviated variable names appears in Table 2).

Abbreviation/ Definition	
D_j	Julian Date
D_0	Julian date of minimum FMC
ELV	Elevation above sea level (m)
FMC	Foliar moisture content (%)
LAT	Latitude (degrees)
LATN	Normalized latitude (degrees)
LON	Longitude (degrees)
ND	Number of days between the current date and D_0

Table 2

In the FBP System the prediction of the basic rate of spread (RSI) is based on the general equation

$$RSI = a \times \left[1 - e^{-b \times ISI}\right]^{c} \quad (1)$$

where a, b, and c are empirically defined quantities which vary for each fuel type (Table 2).

The basic rate of spread (RSI) is then adjusted according to the Buildup Index (BUI) which is an indicator of the amount of fuel available for combustion. This occurs through the buildup effect (BE) calculated by

$$BE = e^{\left[50 \times \ln(q) \times \left(\frac{1}{BUI} - \frac{1}{BUI_0}\right)\right]} \quad (2)$$

where BUI, and q are specified parameters for each fuel type (Table 3). The buildup effect (BE) serves as a multiplier to the RSI and, for the C-6 fuel type, produces the surface fire rate of spread (RSS) by the equation

$$RSS = RSI \times BE. \quad (3)$$

Fuel	a	b	c	Q	Uo	CBH	CFL
C-1	90	0.0649	4.5	0.90	72	2	0.75
C-2	110	0.0282	1.5	0.70	64	3	0.80
C-3	110	0.0444	3.0	0.75	62	8	1.15
C-4	110	0.0293	1.5	0.80	66	4	1.20
C-5	30	0.0697	4.0	0.80	56	18	1.20
C-6	30	0.0800	3.0	0.80	62	7	1.80
C-7	45	0.0305	2.0	0.85	106	10	0.50

Table 3
Rate of Spread Parameter Values for Each Fuel Type

For the C-6 fuel type only, the crown fire rate of spread (RSC) is also calculated, using the equation

$$RSC = 60 \times \left(1 - e^{-0.0497 \times ISI}\right)^{1.00} \times \frac{FME}{FME_{avg}} \quad (4)$$

where the average foliar moisture effect (FME_{avg}) is a constant value of 0.778 and the foliar moisture effect (FME) is computed using the equation

$$FME = \frac{(1.5 - 0.00275 \times FMC)^{4.0}}{460 + (25.9 \times FMC)} \times 1000 \quad (5)$$

In equation 5, FMC refers to the foliar moisture content, which is derived from the following equations (see Table 2 for definitions of the terms).

$$FMC = 85 + 0.0189 \times ND^2 \qquad ND < 30 \quad (6)$$

$$FMC = 32.9 + 3.17 \times ND - 0.0288 \times ND^2 \qquad 30 \leq ND < 50 \quad (7)$$

$$FMC = 120 \qquad ND \geq 50 \quad (8)$$

$$ND = |D_j - D_0| \quad (9)$$

$$D_0 = 142.1 \times \left(\frac{LAT}{LATN}\right) + 0.0172 \times ELV \quad (10)$$

$$LATN = 43 + 33.7 \times e^{-0.0351 \times (150 - LON)} \quad (11)$$

The final rate of spread (ROS) for the C-6 fuel type will lie somewhere between the surface fire rate of spread (RSS) and the crown fire rate of spread (RSC), depending on the degree of crown involvement or crown fraction burned (CFB), as shown by the equation

$$ROS = RSS + CFB \times (RSC - RSS). \quad (12)$$

The crown fraction burned (CFB) is computed from

$$CFB = 1 - e^{-0.23 \times (RSS - RSO)} \quad (13)$$

where RSO, the critical surface fire rate of spread, is determined by the equation

$$RSO = \frac{CSI}{(300 \times SFC)}. \quad (14)$$

The critical surface fire intensity (CSI) is given by

$$CSI = 0.001 \times CBH^{1.5} \times (460 + 25.9 \times FMC)^{1.5} \qquad (15)$$

where CBH is the height to the live crown base (given in Table 3) and FMC is calculated using equations 6 - 11. Surface fuel consumption (SFC) is calculated for the C-6 fuel type using the equation

$$SFC = 5.0 \times \left(1 - e^{-0.0149 \times BUI}\right)^{2.48} . \qquad (16)$$

The difficulty in the software environment is in supporting the mathematics of this process without, at the same time confusing the user. If the fuel variable is ignored, then the parameters that create the variations in CSI, RSO and CFB are almost the same. Figure 3 shows the present implementation of this process.

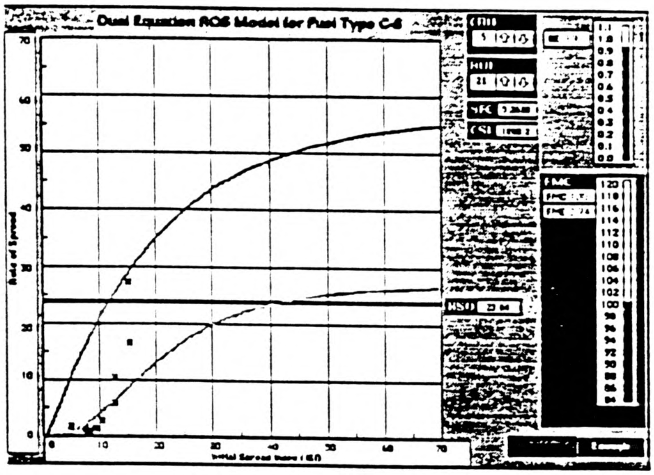

Figure 3
Interactive Evaluation of Crown Surface Fire Transition

Note that in Figure 3 there are four parameters (BE, FMC, CBH, BUI) whose values can be modified with controls. The first two have standard value ranges: [0,1] for BE and [85,120] for FMC. The latter two parameters, CBH and BUI, are modified by the fuel type, so that there is no standard fixed range for the values, although there are realistic upper limits. In this interactive environment, SFC, CSI and FME are dynamically computed as the controls are adjusted. More importantly for the user, however, is the feature that, since the crown spread rate curve and the surface spread rate curve depend on the input parameters, the curves are dynamically computed and the value of RSO, as well as the line indicator for it, are dynamically positioned to show the changed crown fire threshold. Note that the BE and BUI values are not independent mathematically and, therefore, adjustment in one of these controls causes changes in the setting of the other. These two quantities are of practical and theoretical importance to the prediction process, however, and it is therefore necessary for the user to be able to manipulate these factors. It is, of course, perfectly possible that, for the given fuel type, fire and climatic conditions, a crown fire simply cannot develop. This situation typically arises when the CBH value is large and the ISI and BUI values, which have input into the fire intensity, are small. In this case, the RSO value and indicating line will lie totally above the lower curve, indicating the impossibility of crown engagement. The opposite situation arises for small values of CBH, where almost all fires move into the same state of crowning because the RSO value is small. The indicating line, in this case, is almost coincident with the horizontal axis.

Concluding Remarks

As stated previously, there has been a substantial amount of support for this multimedia system, and for the general approach to representing information. It is presently planned that it will be used in Advanced FBP System training courses at the Forest Technology School in Hinton, Alberta and that the software will be made available to FBP System users. An active effort is also being made to investigate the construction of isomorphic systems on other GUI computing platforms.

The multi-disciplinary group involved in this three year prototype study has benefited enormously from the variety and challenge of the problems considered and the need for more collaborative efforts of this type has become obvious. A typical recently suggested example is the need to investigate the structure of the *information* and its *accessibility* in the scientific documentation of wildfires, experimental fires and prescribed burns. The information is collected so that research papers and predictive training environments can be developed to assist forest management agencies. Mechanisms to manipulate this information, so that hypotheses and comparisons can be formulated about seemingly disparate events, would be of great importance.

Acknowledgement

The authors would like to acknowledge the co-operation and assistance of the members of the Forestry Canada Fire Danger Group: Rob McAlpine, Brian Stocks, Tim Lynham, Marty Alexander, Bryan Lee and Bruce Lawson; the support of Apple Canada in its donation of hardware and software to this project; the Forest Technology School at Hinton, Alberta which acted as an Alpha site; and the Manitoba-Canada Forestry Agreement for partial funding of this project. We would also like to thank the reviewers and program editor for their helpful suggestions.

References

1. Development and Structure of the Canadian Forest Fire Behavior Prediction System, Forestry Canada Fire Danger Group, Information Report ST-X-3, Ottawa, 1992.
2. Development and Structure of the Canadian Forest Fire Weather Index System, Wagner, C.E., Canadian Forestry Service, 1985, Forestry Technical Report 35.
3. A Table of Diurnal variation in the Fine Fuel Moisture Code, Wagner, C.E., Canadian Forestry Service, 1972, Information Report PS-X-38.
4. A Method of Computing Fine Fuel Moisture Content throughout the Diurnal Cycle, Wagner, C.E., Canadian Forestry Service, 1977, Information Report PS-X-69.
5. Combustion of forest fuels, Byram, G.M., Pages 61-89 *in* K.P. Davis, ed., Forest fire: control and use. McGraw-Hill Book Co., 1959, New York.
6. Computer Graphics: Tools for Visualization, Morris W. Firebaugh, Wm. C. Brown Publishers, 1993, University of Wisconsin-Parkside.

A number of the figures, tables and equations in this paper were used or adapted with permission of the Fire Danger Group.

This work was sponsored in part by the Canada-Manitoba Partnership Agreement in Forestry under Contribution Agreement Number 1991/92-5007.

'94 SYMPOSIUM ON APPLIED COMPUTING (SAC'94) CALL FOR PAPERS AND PARTICIPATION

March 6-8, 1994 – Phoenix Civic Plaza

SAC'94 Conference Themes:
"Strategic Technology Transfer" and "Intelligent Business Applications"

CONFERENCE CHAIR:
Hal Berghel, University of Arkansas

PROGRAM CO-CHAIRS:
Terry Hengl, Knowledge Technology, Inc. and PC AI Magazine
Joseph Urban, Arizona State University

CONFERENCE DIRECTOR:
Edmund Deaton, San Diego State University

STEERING COMMITTEE:
Elias Awad, (SIGBIT)
Hal Berghel, University of Arkansas
George Hedrick, Oklahoma State University
Dick Hetherington, Univ. of Missouri–Kansas City
Abe Kandel, University of South Florida
S. Lakshmivarahan, University of Oklahoma
Irving Montanez, Brookhaven Labs (SIGFORTH)
Bill Poucher, Baylor University
Roy Rada, University of Liverpool (SIGBIO)
Lynne Shaw, Consultant (SIGAPL)
John Talburt, University of Arkansas–Little Rock
Glenn Thompson, AMOCO
Beth Unger, Kansas State Univ.(SIGSMALL/PC)
Joseph Urban, Arizona State University
Roger Wainwright, University of Tulsa
Kam-Fai Wong, ECRC

Direct general inquiries to the Conference Director:
Ed Deaton, Dept. of Mathematical Sciences, San Diego State University, San Diego, CA 92182 (voice: 619-594-5962; fax: 619-594-6746; deaton@cs.sdsu.edu)

Send submissions and proposals for panels, tutorials and workshops to one of the Program Co-Chairs:
Joseph Urban, Dept. of Computer Science and Eng., Arizona State University, Tempe, AZ 85287 (voice: 602-965-2774; fax: 602-965-2751; jurban@asuvax.eas.asu.edu)

Terry Hengl, PC AI Magazine, 3310 West Bell Road, Suite 119, Phoenix, AZ 85023 (voice: 602-971-1869; fax: 602-971-2321; 0004077516@mcimail.com)

For more information on SAC and the ACM Special Interest Group on Applied Computing, contact SAC'94 Conference Chair and SIGAPP Chair:
Hal Berghel, Computer Science, University of Arkansas, Fayetteville, AR 72701 (voice: 501-575-7343; fax: 501-575-7342; hlb@acm.org)

SAC'94

SAC is the annual conference of the ACM Special Interest Group on Applied Computing (SIGAPP). For the past eight years, SACs have become a primary forum for applied computing practitioners and researchers. Once again, SAC'94 will be held in conjunction with the 1994 ACM Computer Science Conference in Phoenix. This year, SAC'94 will bring together five additional ACM Special Interest Groups: SIGAPL, SIGBIO, SIGBIT, SIGFORTH and SIGSMALL/PC, each one of which will have their own track within SAC'94.

Although papers and proposals for panels, tutorials and workshops which deal with the conference themes, STRATEGIC TECHNOLOGY TRANSFER and INTELLIGENT BUSINESS APPLICATIONS, are especially encouraged, papers which deal with all areas of applied computing are solicited. Of particular interest are papers in AI, Biomolecular Computing, Cognitive Science, Computational Biology-Chemistry-Physics and Geosciences, Reliability, Electronic Libraries, Multi-Media, Geographic Information Systems, Image Processing, Logic and Symbolic Programming, Office Automation, Software Reusability and Intelligent Systems. Proposals for special sessions and panels are also encouraged.

IN BRIEF...
SAC'94 will begin on Sunday, March 6, 1994, with pre-conference tutorials. Paper presentations and panels will begin on Monday, March 7. For further information contact addresses listed above.

GUIDELINES FOR SUBMISSION...
Original papers dealing with any aspect of computing applications will be considered for presentation and publication in the SAC'94 Proceedings. This specifically includes these categories of submissions: (1) original and unpublished research, (2) reports of innovative applications in the arts, sciences, engineering, business, government and industry, and (3) reports of successful technology transfer to new problem domains. Each category of submission will be reviewed by peer groups appropriate to that category. Accepted papers in all categories will be published in the Conference Proceedings. Expanded versions of selected papers from all categories will be considered for publication in the ACM/SIGAPP quarterly *Applied Computing Review*.

In order to facilitate the blind external review process, submission guidelines must be strictly adhered to:

- Submit 5 copies of original manuscripts to Joseph Urban, Conference Co-Chair, at the address above.
- Author name(s) and address(es) MUST NOT appear in the body of the paper, and self-reference should be in the third person.
- The body of the paper should not exceed 5,000 words (20 pages, double-spaced) without prior approval.
- A separate cover sheet should be attached to each copy, containing (1) the title, (2) the author(s) and affiliation(s), and (3) the address (including e-mail and fax) to which correspondence should be sent.
- Papers relating to SIGAPL, SIGBIO, SIGBIT, SIGFORTH and SIGSMALL/PC participation should be clearly identified as such so that they may be directed to appropriate track chairs. Look for further information in these SIG newsletters.

All papers and panel proposals must be received by October 1, 1993.