Natural Sciences and Engineering Research Council of Canada | Conseil de recherches en sciences naturelles et en génie du Canada

Institutional Identifier

FORM 101

Application for a Grant

PART I

Date: 2010/04/15

System-ID (for NSERC use only): 130565826

Family name of applicant	Given name	Initial(s) of all given names	Personal identification no. (PIN)
Fisher	Brian	BD	239168**Valid**

Institution that will administer the grant: Simon Fraser

Language of application: English / French **X**

Time (in hours per month) to be devoted to the proposed research / activity: 15

Type of grant applied for: Strategic Project Grants

For Strategic Projects, indicate the Target Area and the Research Topic; for Strategic Networks indicate the Target Area.

Safety and Security / Risk and Vulnerability

Title of proposal: Visual analytics for Emergency Management

Provide a maximum of 10 key words that describe this proposal. Use commas to separate them.

visualization, tabletop computing, emergency response, emergency preparedness, mixed-initiative computing, visual analytics, cognitive systems, decision-making

Research subject code(s)		Area of application code(s)	
Primary	Secondary	Primary	Secondary
2710	7001		8041207

CERTIFICATION/REQUIREMENTS

If this proposal involves any of the following, check the box(es) and submit the protocol to the university or college's certification committee.

Biohazards / Humans / Research involving : **X** Human pluripotent stem cells / Animals

Does any phase of the research described in this proposal a) take place outside an office or laboratory, or b) involve an undertaking as described in Part 1 of Appendix B?

NO **X** — If YES to either question a) or b) – Appendices A and B must be completed

TOTAL AMOUNT REQUESTED FROM NSERC

Year 1	Year 2	Year 3	Year 4	Year 5
151,825	152,825	152,825	0	0

SIGNATURES (Refer to instructions "What do signatures mean?")

It is agreed that the general conditions governing grants as outlined in the NSERC to this application and are hereby accepted by the applicant and the applicant's employing institution.

Program Guide for Professors apply to any grant made pursuant

Head of department / Applicant

Applicant's department, institution, tel. and fax nos., and e-mail

Interactive Arts and Technology, School of (SIAT)
Simon Fraser
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Tel.: (778) 782-7554
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The information collected on this form and appendices will be stored in the Personal Information Bank for the appropriate program.

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Dean of faculty

Version française disponible

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CO-APPLICANTS

I have read the statement "What do signatures on the application mean?" in the accompanying instructions and agree to it.

PIN, family name and initial(s)	Research/ activity time (hours/month)	Organization	Signature
18082, Dill, J	5	Simon Fraser	
307674, Blair, M	10	Simon Fraser	
206566, Irani, P		Manitoba	
12284, Borwein, P		Simon Fraser	

CO-APPLICANTS' ORGANIZATIONS AND/OR SUPPORTING ORGANIZATIONS (if organization different from page 1)

It is agreed that the general conditions governing grants as outlined in the NSERC *Program Guide for Professors,* as well as the statements "What do signatures on the application mean?" and "Summary of proposal for public release" in the accompanying instructions, apply to any grant made pursuant to this application and are hereby accepted by the organization.

Family name and given name of signing officer, title of position, and name of organization	Signature
Melanie Dutkiewicz R & D Team Manager MacDonald Dettwiler & Associates Nancy Clos Associate Director, Office Research Serv Manitoba Dave Cross Manager of Development EmerGeo Solutions Gamal Mustapha President SMT Research Ltd.	

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CO-APPLICANTS' ORGANIZATIONS AND / OR SUPPORTING ORGANIZATIONS (if organization different from page 1)

Family name and given name of signing officer, title of position, and name of organization	Signature
Russell Cork VA Development Manager Smart Technologies	

Use additional page(s) if necessary.

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Before completing this section, read the instructions for the definition of collaborators in the Eligibility Criteria section of the Program Guide for Professors.

COLLABORATORS

PIN, family name and initial(s)	Research/ activity time (hours/month)	Organization
MacEachren, A	5	Pennsylvania State University
Ebert, D	5	Purdue University
Haselkorn, M	5	University of Washington
Ribarsky, W	5	University of North Carolina at Charlotte

Use additional page(s) if necessary.

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SUMMARY OF PROPOSAL FOR PUBLIC RELEASE (Use plain language.)

This plain language summary will be available to the public if your proposal is funded. Although it is not mandatory, you may choose to include your business telephone number and/or your e-mail address to facilitate contact with the public and the media about your research.

Business telephone no. (optional): (778) 782 7554 bfisher@sfu.ca

E-mail address (optional):

Visual analytics, "the science of analytical reasoning facilitated by the interactive visual interface", seeks to develop an evidenced-based approach to the design and evaluation of cognitive systems comprising one or more human decision-makers supported by advanced information and communication technology. We apply the VA approach to emergency management and preparedness. For emergency preparedness we support analysis and evaluation of risk and vulnerability, including novel threats (e.g. terrorism) and innovative approaches to preventing and countering them. For emergency response we implement technology to support a robust "system-of-systems" approach to interoperability. For both we examine the impact of changes in information technology (e.g. social software, sensor technologies) and how they might be utilized to support (or if not controlled, may impair) emergency preparedness and response. We will address four aspects:

1) Graphical visualizations that combine raw data about emergency situations and management activities with computational, statistical and mathematical models of events.

2) Interaction methods for these mixed-initiative visualization systems that enable co-located and distributed multifunctional teams to analyze situations and coordinate their activities in real time.

3) Scientific investigation of how VA technologies effect human cognitive and communicative processes, for system design and customization for individual users, organizations, roles and tasks.

4) Technology integration studies that insure that our scientific findings, technologies and analytical methods are relevant and effective for their target users, organizations, and conditions of use in real-world emergency management situations.

Other Language Version of Summary (optional).

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ACTIVITY SCHEDULE
(Refer to instructions to see if this section applies to your application. Use additional page(s) if necessary.)

Milestone	Description of activities	Anticipated starting date	Anticipated completion date
Understanding emergency management	Initial field work with emergency management team at City of Richmond and EmerGeo researchers	2011-01-07	2011-02-15
Technology integration in emergency preparedness	3 pair analytic sessions conducted with emergency preparedness analysts and emergency response decision-makers	2011-03-15	2011-06-01
Technology integration in emergency operations	Observation & analysis of tabletop or field emergency management exercise at City of Richmond	2012-01-30	2012-04-01
Technology integration in emergency preparedness 2	Emergency Planning application pair analytics session with subject matter expert (e.g. EmerGeo, City of Richmond) and customized OTS or prototype on SMART Technologies display	2012-04-01	2012-05-01
Technology integration for Virtual EoC 2	Command & control application pair analytics session with subject matter expert and customized OTS or prototype on SMART Technologies display	2013-01-07	2013-05-01
Technology integration for Virtual EoC 2	Virtual EoC groupware pair analytics session with subject matter expert and customized OTS or prototype in mixed display environment	2013-01-15	2013-09-01
Analytic cognitive psychometrics	Empirical studies of individual differences, psychometric measures vs interactive visualization performance	2011-01-07	2011-07-01
Visual cognition in analytics	Experimental test using eyetracking technologies for analytic task	2011-02-01	2011-09-01

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Milestone	Description of activities	Anticipated starting date	Anticipated completion date
Visual cognition in analytics 2	Submission of whitepaper/publication of dynamic model of information access and decision making based on eye-tracking work	2011-10-01	2012-01-01
Visual cognition in emergency planning	Cognition study examining problem solving in prototype VA environment using emergency planning scenario	2012-05-01	2012-10-01
Visual cognition in emergency operations	Study of changes in cognitive performance due to time pressure with implications for emergency operations management	2012-12-01	2013-07-01
Distributed cognition in emergency operations	Study of vulnerabilities in operational communication with recommendations for design of visual analytic applications and supporting technologies	2011-03-01	2012-09-01
Distributed cognition in emergency operations 2	Whitepaper/publication advancing joint activity theory to generate a model of real-time collaborative emergency operations management	2012-09-15	2013-01-01
Distributed cognition in emergency operations 3	Distributed cognition study examining collaborative system-of-systems problem solving in prototype VA environment using emergency operations scenario	2012-02-01	2012-07-01
Distributed cognition in emergency planning	Whitepaper/publication advancing joint activity theory to generate a model of proactive collaborative emergency planning	2012-07-15	2013-10-30
Cognitive models for interactive visualization	Initial implementation of rule-based intent agent using a simple interactive information visualization with a small dataset	2011-08-01	2012-01-01

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ACTIVITY SCHEDULE
(Refer to instructions to see if this section applies to your application. Use additional page(s) if necessary.)

Milestone	Description of activities	Anticipated starting date	Anticipated completion date
Cognitive models for interactive visualization 2	Implementation of agent memory and decision making. Testing of the agent and agent decisions through usability studies.	2012-02-01	2012-07-01
Cognitive models for interactive visualization 3	Enhanced logic (e.g. fuzzy-Bayesian) agent with a larger, more semantically complex dataset	2012-08-01	2013-01-30
Technology integration in emergency preparedness	UM study of SMT sensor planning in building architecture and construction	2011-02-01	2011-04-01
New technologies for emergency preparedness	SMART Tabletop display study of SMT sensor planning in building architecture and construction		
New technologies for emergency preparedness 2	SMART Wall & tabletop display study of SMT sensor planning in building architecture and construction	2011-07-01	2011-11-30
interactive Visualization for emergency preparedness	CZSaw integration of cognitive "chunking" and procedures derived from field work	2011-02-01	2011-03-30
interactive Visualization for emergency preparedness 2	CZSaw implemented in emergency preparedness scenario	2011-09-01	2012-04-30
interactive Visualization for emergency preparedness 3	CZSaw emergency preparedness user evaluation with subject matter expert (e.g. EmerGeo, City of Richmond) on SMART Technologies display	2012-05-01	2012-09-01

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ACTIVITY SCHEDULE
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Milestone	Description of activities	Anticipated starting date	Anticipated completion date
Visualization of vaccine response data user evaluation with	Integrate MOCCSy simulation of social system in prototype (e.g. pandemic spread model)	2012-09-01	2013-06-30
Communication of Results 1	First workshop on visual analytics in partnership with JIBC in Vancouver	2011-11-01	2011-11-01
Communication of Results 2	Second workshop on visual analytics in Ottawa	2012-11-01	2012-11-01
Communication of Results 3	Final workshop on visual analytics, location TBD	2013-11-01	2013-11-01
interactive Visualization for pandemic preparedness	Visualization of vaccine response data user evaluation with subject matter expert (e.g. EmerGeo, City of Richmond)	2012-01-01	2013-06-30

Relationship to other research support

B. Fisher: Boeing Support for Visual Analytics in Canada (Fisher subgrant) ($15K Boeing).
Will expire before the proposed project takes effect, however we will submit similar proposals for allocation of funds from the UBC-based 2007-2012 grant for expenses associated with Boeing field work e.g. matching funds for the MITACS grant below.

B. Fisher: Program to Evaluate and Improve Visual Analytic Processes and Technology at
Aeroinfo Systems ($160K NSERC/MITACS/Aeroinfo). Partial funding for Dr. Arias-Hernández and five graduate field researchers. Applications of visual analytics for aircraft safety and maintainability. There is no overlap with the current emergency management proposal.

B. Fisher: Deriving and Applying Cognitive Principles for Human/Computer Approaches to Complex Analytical Problems DHS International Program to UNCC/SFU. Total budget,
$300K/1yr, Fisher PI subgrant $64K after overhead. Extending our human cognitive model to make it predictive and practical. Develop evaluation strategies and design principles for visual analytic methods. The model and design principles will be applied to laboratory research in health care (vaccination response). Minimal overlap with the current proposal (e.g. pandemics).

B. Fisher, J. Dill: DHS Center of Excellence in Command, Control and Interoperability ($75K DHS) Work on US DHS Mission-Driven Research Projects to support US Homeland Security Professionals. There are no funds for basic research, and of course, nothing for Canadian situations and policies. It provides connections with US researchers and comparative data on applications that we will mine for insight into analytic processes, thus reducing costs.

J. Dill: Boeing Support for Visual Analytics in Canada (J. Dill subgrant) ($34K Boeing).
This grant will expire before the proposed project takes effect, however we will submit similar proposals in the future to provide funds for expenses associated with understanding Boeing datasets, accordingly we have not budgeted for this expense in our proposal.

J. Dill: Program to Evaluate and Improve Visual Analytic Processes for Analyzing Maintainability, Reliability and Safety Data – Part 1 ($71K NSERC/MITACS/Aeroinfo).
Funding for Postdoctoral Research Associate Dr. Darvill. This will also expire before the proposed project is scheduled to begin, however we hope to use this mechanism to fund graduate students and postdoctoral fellows in the future to analyze aircraft maintenance and safety data.

M. Blair. Selective Processing of Features, Dimensions and Feedback in Human Category

Visual Analytics for Emergency Management

1. Introduction

We hold that the primary barrier to acceptance of advanced Information and Communication Technology for emergency management is the inability of human decision-makers to understand the volumes of complex data that these technologies make available to them. Visual analytics addresses the gap between ICT capabilities and the human ability to reason, understand, and communicate about disasters and recovery operations. The advantages of modern sensor, satellite, and ICT technologies come at the cost of the need to reconcile information from a diversity of sources, reconcile conflicts between them and the uncertainties in fact, time and place of occurrence of events that they describe. Above all, the sheer size of the data that may in principle inform assessment and management of risk and vulnerabilities is increasing exponentially. This challenge of data management and interpretation pose the primary obstacle to the acceptance and utilization of advanced ICT and sensor technology in emergency management. We directly address this challenge with VA tools and techniques.

We are submitting this proposal under **Risk and Vulnerability** within the **Safety and Security** theme: "*Decisions pertaining to safety and security must be based on an in-depth understanding of risks and vulnerabilities, and must be seen by citizens as rational, transparent, and defensible. Researchers are encouraged to focus their proposals on the development of techniques, tools and systems that strengthen our capacity to identify and measure risks and vulnerabilities, weigh and compare different types of risks, determine risk levels and inform decision-makers.*" We see three challenges in this. First, risk and vulnerability are complex and ill-defined constructs, with "unknown unknowns" (data anomalies that might indicate new vulnerabilities e.g. the 9/11 attacks) as well as "known unknowns" (e.g. storm surge level). Thus the need to "identify and measure risks and vulnerabilities" requires analysts to discover novel patterns as well as to detect known patterns in data. This is described in the VA catchphrase "to detect the expected and discover the unexpected". Second, the need to "inform decision-makers" requires ongoing assessment of risks and vulnerabilities associated with actions taken in the field (operational risks). To be actionable and effective, assessment of risk and vulnerability must support and be integrated with the systems of command, control, and interoperability in disaster relief. Third, rational, transparent, and defensible decisions and processes must address management of media, including new media, (blogs etc.) as they occur. Lastly and most importantly, we recognize that "in-depth understanding" is a product of human cognition. No attempt to support a process can succeed unless that process is understood and metrics of it are used for assessing the success of the system. Thus any attempt to use ICT to enhance understanding of risk and vulnerability requires that developers have a scientific understanding of human cognitive capabilities and metrics by which they can be assessed, grounded in knowledge of the characteristics of the complex and evolving situations that must be understood. This is central to our work.

We focus on analysis and evaluation of risk and vulnerability, including novel threats and innovative approaches to preventing and countering them. This applies most clearly to threats from human activity, i.e. terrorism, but also to analysis of the changing information environment (e.g. social software) that can impair but might also support preparedness and response. Our response work supports the use of new technologies (e.g. wireless data links, sensors, handheld devices and touchscreen displays) to support a robust, networked, "system of systems", e.g. a "Virtual Emergency Operations Centre".

2. Research Proposal

Visual Analytics " **the science of analytical reasoning facilitated by the interactive visual interface**" [1] directly addresses the gap between the capabilities provided by ICT and the human ability to reason, understand, and communicate about the situations and actions that contribute to effective emergency management. VA was first described in the 2004 IEEE Press book "Illuminating the Path: A National Research Agenda in Visual Analytics". This set forth an ambitious research agenda bridging scientific research in human analytic reasoning with methods for graphically representing and manipulating information. The goal of VA is to build a science to guide development of mixed-initiative human/computer analytic systems. In 2005 a substantial VA research effort was funded by the US Department of Homeland Security (DHS) and implemented by the Pacific Northwest National Laboratory's National Visualization and Analytics Centre (PNNL-NVAC) and five Regional VA Centres led by Purdue, Stanford, Georgia Tech, U. North Carolina-Charlotte, Penn State/Drexel, and U. Washington. This collaboration expanded with the addition of Virginia Tech and others to give rise to VACCINE, the US Department of Homeland Security Center of Excellence in Command Control and Interoperability. A European Coordination Action Project *VisMaster* was launched in 2008 with 33 institutions in 12 countries.The level of investment in VA in the US and Europe in VA research suggests that it may soon become important part of their procurement strategy. The time is right for Canadian technology and service providers to explore how VA can be used in their products and services.

Using a VA approach for emergency management necessarily requires us to understand emergency management tasks and systems from end to end: **data generation** by sensors, satellite imagery etc. **information routing and handling** via middleware and guided by experts in data fusion centres. We must understand **analytic planning** systems for emergency preparedness, and **command and control** systems for emergency response. Canadian technology providers address many of these areas:

Sensor and middleware makers SMT Research and Solace Systems enable the collection and routing of data that VA systems must utilize. Advanced interaction systems made by SMART Technologies are used in CCI and collaboration. For these companies, advanced knowledge of the needs and abilities of VA systems will enable them to customize their existing product line and quickly develop new products.

MacDonald Dettwiler's Integrated Information Solutions group builds end-to-end large scale systems for command, control, communication, computer intelligence, surveillance, and reconnaissance with the goal of fusing static and dynamic data sources into comprehensive, obtainable information for real-time decision making in the field. For them, VA provides a new approach to the development of interfaces to handle complex information spaces that is of interest to potential clients.

Oculus and EmerGeo build mid-size analytics, GIS, and data integration systems, like MDA they will directly benefit from the prototypes we develop in our labs and adapt from our partners in the DHS. While MDA typically focuses on large-scale contract development systems, Oculus and EmerGeo have focused on local and regional analytic, data fusion and emergency operation centres. Many of these interfaces utilize symbols designed by Refractions Inc. of Victoria BC, and we are in contact with them.

Finally, emergency management requires strong links to government stakeholders. Examples include Natural Resources Canada's GeoConnections, home of Canada's Geospatial Data Infrastructure. They provide spatial database and symbology standards ad well as the actual databases. Policies for emergency management systems and interoperability come from DRDC, the Centre for Security Science, and the Canadian Police Research Centre. The policies they set must inform design of technology used in Canada. Our discussion with Amy Romanas the City of Richmond's Emergency Program Coordinator will give us a more specific view of the pragmatics of emergency management in a location that faces potential threat

island, hence bridge failure is a concern). Richmond is also the home of Vancouver Airport, which is important for the lower mainland in any case, and particularly so in the case of a major disaster.

Richmond's strong interest in a "virtual EOC" stems from their situation. We believe that our new Canadian business and government partners will enable us to transition work done in an international context to achieve four objectives for Canada:

2.1 Objectives

1) In collaboration with stakeholders (City of Richmond, Justice Institute of BC, and possibly others); system developers (EmergGeo, MacDonald Dettwiler, and Oculus); and our international VACCINE partners we will adapt existing information systems to better utilize interactive visualization interfaces for current emergency management practices and policies.

2) We will advance new analytical methods and technologies that take into account innovations in Canadian policies (e.g. Capability Based Planning, System of Systems). We will do this in collaboration with our contacts in the Federal Government (e.g. CBRNE Research and Technology Initiative, Canadian Police Research Centre). Technologies include tabletop and wall displays and small form-factor systems, and can be extended new partners and uses, e.g. pandemic monitoring.

3) We will work with Solace, SMART, and SMT to determine how the changing world of VA-based end-user information technologies will create new directions for research in the supporting information infrastructure-- sensors, communication links, data processing, etc.

4) Build the science of VA as both a practical and effective approach to the design and implementation of emergency management ICT, and as a progressive cognitive science that advances new theories, and proposes and tests strong hypotheses about mixed-initiative visual information systems.

5) Support training of VA HQP for our current VA students and those in our proposed VA graduate certificate program. We will work with Justice Institute of BC to extend to train first responders.

These objectives are captured in milestones. Objectives 1 and 3 most generally contribute to the Technology Integration milestones, Objective 2 to Interaction Methods and Graphical Visualizations, and Objective 4 to Scientific iInvestigation. Objective 5 is picked up in the HQP page.

2.2 Approach and methodology

To apply VA methods to understanding risk and vulnerability for emergency management we must devise new and more effective methods for understanding the needs of real-world organizations and individuals responsible for predictive analysis of risk and vulnerability for emergency preparedness and managing operational risks in emergency management. These must be accurate and precise enough to formulate research questions for our experimental work as well as guiding the design and testing of new visual information systems. The approach taken by VACCINE, the US DHS Center of Excellence in VA combines core research in foundations, analytical techniques, and technology environments with Mission-Driven Research Projects (MDRPs). MDRPs partner university researchers with homeland security professionals, with requirements for validation and testing and a clear technology transition plan. We follow this example on a smaller scale in this application, placing our emphasis on the integration of Canadian technology providers and government bodies in the research. This insures that we are able to build technologies in Canada, in consultation with Canadian emergency managers, that are consistent with current and emerging Canadian policies. Our collaboration with 16 major US universities in VACCINE, the US National VA Centre, and other 11 university-based DHS centers of excellence places us in a unique situation with regard to our ability to conduct this research.

Application-driven research questions differ markedly from those in curiosity-driven cognitive science research, and so we must build new experimental methods that provide fundamental understanding of

"cognition in the wild": cognitive processing by real world analysts and decision makers, their organizations, and the situations in which they must function. Groundwork for this approach has been laid by our Boeing/MITACS projects and a one-year US DHS International grant "Deriving and Applying Cognitive Principles for Human/Computer Approaches to Complex Analytical Problems".

Research results from cognitive science studies are necessary but not sufficient to provide the level of guidance that engineers and computer scientists require for informed design and effective evaluation of new technologies. Thus we propose to extend our previous work, building new experimental methods that support modeling social and cognitive processes. We expand upon this in the next section. We are requesting funding here for additional work on modeling and studies of cognitive processes.

We must integrate knowledge generated in the field, the laboratory, and through simulation to incorporate them in iterative design of new technologies. The largest part of the funding requested in this proposal is directed to the development and evaluation of new technologies and methods for evaluating its utility in emergency management.

The need to "**identify and measure risks and vulnerabilities"** in the STPG topic area requires an analyst or decision maker to discover novel patterns as well as to detect known patterns in their data. This is well described in the VA catchphrase "to detect the expected and discover the unexpected". One focus of the proposed research is to support analytical insight into novel situations as well as effective management of familiar scenarios, and to support creative and innovative approaches to analysis.

The stated need to "**inform decision-makers**" carries with it a need for ongoing assessment of risks and vulnerabilities (e.g. operational risks) associated with actions taken in the field. Assessment of risk and vulnerability in emergency planning must support and be integrated with the systems that support command, control, and interoperability in disaster relief. In an evolving threat or ongoing disaster situation, units such as fire, police, search and rescue, etc. must be able to function as integral systems, supported by information technology, as they deal with the unfolding situation. They must have the capability to interoperate with other components of the disaster relief effort as well as to respond to command and control from their emergency operations centre. Hence a key goal in this proposal is to counter the dynamic nature of threats by emphasizing the development of technological support for robust response capabilities. We take a "system of systems" approach, building on high-speed optical and wireless communication and new sensor technologies.

Central to our approach is the recognition that the call for **"in-depth understanding"** is a product of human cognition. No attempt to build technologies to support a process can succeed unless that process is understood and metrics of it are used for assessing the success of the overall system. Thus any attempt to use information and communication technology to enhance understanding of risk and vulnerability will require that developers combine a scientific understanding of human cognitive capabilities and metrics by which they can be assessed with knowledge of the characteristics of the complex and evolving situations that must be understood in disaster prevention and managed in disaster relief.

Computer support can compensate for human cognitive limitations such as confirmation bias, base rate neglect etc. [2]. The use of information visualizations also enhances human capabilities to detect patterns and anomalies during emergency preparedness, helping refine mental models and representations of risk and vulnerability [3]. These mixed-initiative human-computer cognitive systems will require new development methods that build upon and direct experimental science that will inform the design and evaluation of new technologies for augmenting human cognitive processing and hence, understanding [4]. Addressing these needs requires an integrated multidisciplinary science [5]. The resulting scientific theories and practical knowledge assets must be integrated in the technology development process.

In order to support analytics in emergency preparedness, management and operations we must understand how a range of experts from emergency managers to first responders plan for and understand situations and how that process is affected by information, time and resource constraints. We propose the following set of hypotheses about this process.

0) In planning and to a greater extent in operations when information, resources and time are limited, the trained and experienced decision-maker uses the cognitive heuristics and scripts that constitute a large part of their expertise to act quickly and effectively.

As information and resources are made available they enter a planning cycle consisting of:

1) Characterizing the situation-- Using their knowledge and experience with available data they chose a strategy, or in cognitive terms, they select an operational mental situation model. The danger here is that if the situation is mis-categorized, information technology can provide confirmatory evidence that will prevent they from reassessing their strategy and choosing the correct path.

2) Assessing the situation, or in cognitive terms, parameterizing their mental model with data (e.g. sensor data, reports from the field) and prior expectation they have gained through training and experience. They use this richer representation to generate "what-if" analysis, predicted outcomes of events, etc. to set priorities and establish tactics. The danger here is that information technology might mask uncertainty in data and lead to poor prediction and misallocation of resources.

3) Engaging the situation through action in the field, monitoring success of those actions in real time and at different levels of command and control. It is at this point that interoperability plays a role, and specific processes support the understanding and coordination of activity with others [6] and ongoing events [7]. The danger here is two-fold, first that sheer volume of data will obscure important events, and second, that a distributed team will not coordinate because they lack the information to do so.

We can characterize this process as a cognitive system, and suggest that it takes place at a number of levels-- in an EoC, in incident command, and by individual first responders. All of these actors bring the same human capabilities to their tasks, and so a scientific understanding of their cognitive processes will support our understanding of how emergency management systems function and coordinate.

2.2.1 Scientific guidance for technology development:

VA was founded on the belief that technology design and evaluation must be guided by science. Here we apply this method to understanding risk and vulnerability in emergency preparedness and response in the context of Canadian policy for emergency management with its emphasis on capability-based planning in a “systems of systems”. We thus focus on applying our work on underlying cognitive science basis for design of technologies to support interoperable analytical and organizational systems. Our systems approach [7] to human reasoning facilitated by close coupling with computational analytic methods (e.g. statistics, AI, “Monte Carlo” methods) is a new direction for the field of VA. This interplay of computational analytics and human cognition creates a new challenge, to understand cognition as a system that is in some respects is distributed between human and algorithm as well as between multiple human decisions makers. For the current project our research goals include:

Models of visual cognition. Interface designers are are well aware of cognitive errors and inefficiencies associated with visual information overload. Research in the Blair lab has shown that limiting access to sources of information also has negative effects in both the short-term and long-term, leading to inefficient decision-making strategies [8]. Blair's lab is developing a dynamic model of information access and decision making which can be used to aid in the identification of optimal visual analytic displays, and further, help time the presentation of information to best facilitate decision making.

development of this model we will better learn how to manage visual complexity to support cognitive processing in the analytic cycle we describe above.

Models of distributed cognitive systems. Substantial cognitive science literature discusses the use of heuristics and scripts in cognitive processing, however it does not directly speak to how heuristics are used "in the wild" in emergency management. Similarly, there is a good deal of research on selection of mental models, and confirmation bias as a mechanism for maintaining a poor selection in the face of contradictory evidence. Our previous work addresses performance of a human/computer cognitive system as a time-linked interaction between display updating and human information processing using the two-visual systems theory of Trevarthan [9] and Pylyshyn's FINST theory [10]. We recently extended this concept to examine systems comprising multiple human collaborating on a task supported by visual analytics systems (forthcoming). The development projects below hold the potential for constraining and advancing these models of human and human/computer cognitive processes.

Creation of psychometric measures that will predict the efficacy of a VA environment and support customization for a given user. This will feed into VA design requirements, and is part of the ongoing exploration in Fisher's lab of "the personal equation of interaction" [11] that characterizes the capabilities of a individual user along some particular dimension of interaction. One key component of the model is the effort to capture the effect of individual operator characteristics (e.g., visual working memory and attentional network efficiency) on the overall performance of the operator/environment couplet. This work can not only enhance the development of better analytic systems, it can help inform the task of selecting and training operators for these systems.

2.2.2. Technology development projects

In the context of testing the interfaces below we will explore issues in spatial cognition, problem solving, exploratory search, attentional systems, and visually-guided motor performance.We have successfully done this in context of air traffic control [12], automotive CAD [13], and aircraft safety analysis (forthcoming). While much of the technology we will use in our research will be built by industry and government partners and stakeholders with our support, we propose to conduct in-house technology-demonstration projects. Our fieldwork and translational science support this effort by providing insight into approaches and guidelines for design and evaluation of these technologies.

Modeling and simulation work (SFU, modeling): New opportunities for collaboration on modeling work have been made possible by the merger of the VACCINE VA proposal (in which Fisher was one of four Directors) with the Homeland Security Center for Dynamic Data Analysis (DyDAn) in the new $30M DHS Command, Control, and Interoperability Center of Excellence. Led by the Discrete Mathematics and Theoretical Computer Science Center, itself a collaboration between Rutgers, Princeton, AT&T, Bell Labs, Telcordia, and NEC, DyDAn will greatly enhance our access to computational tools, data, and expertise in the collaborative projects that our membership in the CCI CoE will call on us to contribute to. This proposal seeks funds to support a collaboration with Modeling of Complex Social Systems (MOCSSy) research and training program, their parent organization Interdisciplinary Research in the Mathematical and Computational Sciences (IRMACS) and MITACS, the Mathematics of Information Technology and Complex Systems Network of Centres of Excellence will provide additional support. A CFI grant is being prepared that would support this collaboration with secure computing infrastructure between our laboratories and if possible to our research partners.

Analytics for novel threats and repercussions (SFU, emergency preparedness): Dill's CZSaw project [14] provides an editable history navigation channel for analytics in addition to multiple visual representations of document collections and the entities within them. In CZSaw user interactions are translated into a script language that drives the underlying scripting-driven propagation system. This

and alternative paths, and a dependency graph showing the underlying logic of the analysis and dependency relations among the results of each step. These tools result in a visual model of the sense-making process itself, enabling analysts to visualize their analysis process, reinterpret the problem, explore alternative paths, extract analysis patterns from existing history, and reuse them with other related analyses. In Fisher's lab, related work focuses on exploratory search behaviour in investigation of potential threats. Exploratory search usually starts with an ill-defined query e.g. to discover unexpected and unanticipated threats. ExplorationMap is a node-link graph visualization system for exploratory search that supports awareness of the analytic process and generation of a mental representation of the area under exploration.

Operational analytics for effective command, control and interoperability (SFU, emergency management): This work will focus closely on the interaction between individuals in the context of

their organizations, their roles, conditions of work, and interaction with individuals and groups from other organizations (e.g. firefighters and police in emergencies). Ongoing examines support for interoperability, distribution of tasks among individual analysts, across an organization and, between organizations. In this real-time collaborative process analysts engage in intertwined processes of sense-

The Internet gives managers access to exponentially growing volumes of unstructured textual data (e.g. uncategorized text) generated daily both offline and on the world wide web, particularly in social media (e.g. flicker, Facebook, youtube, twitter). Analysis can provide useful information about an emergency situation (e.g. Tweets in Katrina) as well as the response to that situation by people (rumours, plans etc.). A good deal of work has been done in VACCINE and NVAC on unstructured text analytics for intelligence analysis. We will build on this to examine the utility of real-time search and streaming real-time feeds of observational and opinion chatter from social media. Visual analytics can help by iteratively and interactively identifying priority text that analysts wants to read. At the individual analysts' level, text analytics provides specialized tools for scaffolding the analytic process and archiving analytic observations and conclusions.

Analytics in collaborative settings (UM/SFU, emergency management). Emergency management is at its core a multi-disciplinary effort, requiring a high degree of collaboration among its participants with potentially diverse backgrounds (e.g. infrastructure issues could include engineers, architects, weather specialists and scientists, pandemic monitoring could involve health care specialists, pharmaceutical experts, and scientists). Visual analytics may require small teams working together with a visualisation to discover new insights, however, current visualisations are designed for a single person operating on a desktop. We will explore and develop interactive information visualisation tools for co-located collaborators, on both wall size and tabletop displays. Irani will work with SMT to inspect and monitor building construction activities by overlapping sensory data on 3D spatial layouts. Irani's team will first explore how SMT users work in teams to perform analytic tasks, such as identifying faulty materials or defective construction practices. The current single-user visualizations at SMT Research will be utilized as it enables users to view actual data (non-synthetic) and will be displayed on large wall displays and tabletop setups. In one study for example, Irani will observe how the analysts switch between the multiple displays and whether spreading the visualizations over multiple displays is effective. In another context, he will observe whether the analysts around a tabletop, for example, are capable of extracting the same information irrespective of orientation. We expect that visualizations designed for single user purposes, spread across multiple displays or viewed under different orientations will adversely affect task performance. From these observations, we will distill key principles and develop visualization prototypes designed for multi-user settings. The SFU team will work closely with UM on technologies and protocols developed in this project, with an eye towards adapting these technologies and approaches to emergency

2.2.3 Technology integration projects

The US DHS Center of Excellence in VA combines core research in scientific foundations, analytical techniques, and analysis and decision making environments with a number of Mission-Driven Research Projects (MDRPs). MDRPs partner us with homeland security professionals working on real projects in situ. This provides not only immediate benefits to homeland security but equally importantly, real-world validation, testing, evaluation and a clear technology transition plan for our research agenda. We continue this approach here on a smaller scale. Our work on **Command, Control and Interoperability Practices** examines analytics in the context of an organization. Our experience with real-world analytics at Boeing Canada's Aeroinfo Systems and US disaster relief and antiterrorism efforts led to a strong focus on how VA technologies are selected, users trained, and the resulting analytic workflows integrated into organizations. The techniques we are using are new (e.g. in-vivo studies of analytical practices [15], joint activity analysis of analytic discourse) and continue to evolve. Under the direction of Postdoctoral Research Fellow Richard Arias-Hernández we will apply methods developed in our work with Boeing and MITACS to bear on our work with the City of Richmond's Emergency Management group. This will involve interviews, observation, and pair analytics sessions. If other emergency management groups become available we will work to involve them in our studies, e.g. we have an agreement to work with a public health research group on a project on the effectiveness of vaccination in individuals and as a way of preventing pandemics. The goal of this work is to insure that the technologies have application and impact on emergency planning and operations in the real world.

2.3 Applicants

Mark Blair brings capabilities for the study of visual attention and categorization and acquisition of expertise as well as skill in recording and analyzing eye movement data to infer cognitive processes. Mark will apply his methods for inferring cognitive operations from eye movements in dynamic visual analytic displays. This will advance our understanding of cognitive processing with visual analytic systems and provide metrics for assessing the performance of those systems in cognitive tasks.

Peter Borwein is the founding Project Leader and currently Executive Co-Director of the IRMACS Centre. He is a Burnaby Mountain Chair at SFU and has been a professor in the Mathematics Department and an Adjunct Professor in Computing Science. His research interests span various aspects of mathematics and computer science, health and criminology modeling and visualization. Borwein will coordinate our collaboration with IRMACS and MoCCSy to support modeling cognitive and social processes as well as models of physical phenomena associated with disasters.

John Dill is Professor Emeritus of Engineering Science and Professor of Interactive Arts and Technology at Simon Fraser University. His primary area of expertise is information visualization and VA. Dill will head the CZSaw effort and will provide expertise in visualization techniques, and act as a liaison with industry partners.

Brian Fisher is an Associate Professor of Interactive Arts and Technology and Director of the Program in Cognitive Science at Simon Fraser University as well as the Associate Director of the UBC Media And Graphics Interdisciplinary Centre. He is a member of the Leadership Board of the US DHS Center for Excellence in Command, Control, and Interoperability. Fisher's role is project management, interaction science, technology evaluation methodologies and design guidelines. He also supervises many of the graduate students who will implement and evaluate proof-of-concept interfaces.

Pourang Irani is an Assistant Professor in Computer Science at the University of Manitoba, his contribution will be in building and evaluating interactive technologies for emergency management analysis and response, informed by theories and methods from perceptual and cognitive science.

3. Training Plan

Our training plan contains several components: a new Graduate Certificate in Visual Analytics, active ongoing student exposure to Visual Analytics technologies and methods, and an emergent collaboration with the Justice Institute of BC.

First, we have developed a Graduate Certificate in VA, which has been approved in principle by the Graduate Program Committee of the School of Interactive Arts and Technology, as well as by the School of Communication and the Steering Committee of the Program in Cognitive Science at SFU. The methods we will develop in this proposed project will impact the design of the VA Certificate and its course instructional content by bringing the hands-on exposure of applied methodology to the classroom. Further, our VA cognition courses in particular will benefit from analytical reasoning illustrations drawn from the ongoing work of this project. The Certificate will be to any Masters student at SFU, and through the Western Deans' agreement, likely available for students in BC, Alberta, Saskatchewan, and Manitoba. In addition to our experience with emerging techniques, our previous experience with telelearning technologies can support this distance collaboration in both Canadian universities as well in US institutions such as our colleagues in VACCINE. Because there is funding for such collaborations in the US, we foresee broader coordination with our US colleagues.

Secondly, this proposed project will offer students the opportunity to work with industry and government partners, both in Canada and abroad, and in many cases be funded either by these partners and/or by MITACS. Student RAs will conduct the core research, and will learn our methods by immersion as they advance the research both in the lab and in practice. Because VA is a multidisciplinary field, students will be exposed not only to new concepts in their chosen knowledge domains, but also to the theories and practices of other VA-related disciplines. We will continue to coordinate the use of MITACS internships and Strategic Project Grant RA funding for students, providing a complete training experience by leveraging Strategic Project Grant funding. In addition, we have an agreement for the exchange of students with leaders of the EU Coordination Action and the DFG Priority Program in VA, and have partnered on an NSF Integrative Graduate Education and Research Traineeship grant for student exchanges and other collaboration opportunities with Georgia Tech U., U. Houston, INRIA, U. Konstanz, Penn State U. , Purdue U., U. Stuttgart, Swansea U, and U.

North Carolina Charlotte. Through our partnership with DHS (VACCINE CCI and NVAC) we have access to modules on analytic understanding (e.g. Analytic Mindsets, Uncertainty and Bias), and methods (Analysis of Competing Hypotheses), topics (Intelligence Analysis, Indications Based Warning, Techno-social Predictive Analytics, Environmental Biomarkers), and technologies (e.g. Implications of Structured and Unstructured data, Data-Intensive Computing, and use of GeoTime, nSpace, IN-SPIRE, Analyst's Notebook, Starlight, Jigsaw etc.). These modules and technologies will be utilized in our student training programme, and will emphasize the integration of field and lab methods in interdisciplinary visual analytics research.

Finally, the SFU research group has developed a collaboration with the Justice Institute of BC, whose stated objective is education in public safety venues, including areas of concern to emergency management. Through the Institute, our students will have access to domain experts and specialized data, as well as a broad exposure to relevant knowledge proficiencies that have direct influence on the development of

4. Interaction with Partners

Irani's lab will work closely with SMART, SMT and Solace. The companies will will supply knowledge of the capabilities and requirements of the technologies they produce, as well as R&D directions and interests. Irani's team will first explore how SMT users work in teams to perform analytic tasks, such as identifying faulty materials or defective construction practices. The current single-user visualizations at SMT Research will be utilized as it enables users to view actual data (non-synthetic) and will be displayed on large wall displays and tabletop setups made by SMART. This will entail frequent meetings and visits by their staff to UM labs for studies and research planning.

SFU researchers will work to a greater extent with systems developers EmerGeo, MDA, and Oculus. MDA has had a long history of support for the SFU team, including as partners on a previous STPG "Visual Analytics for Safety and Security" project. They will meet with SFU researchers in Richmond, and we will continue our presentations of research findings at their meetings on at least a semester basis. We have had the benefit of frequent telephone and email communication with Melanie Dutkiewicz on our previous NSERC STPG project. She has directed us to a number of MDA researchers with compatible projects, which lead to our partnership with MDA on a contract application to Defence Canada. We are pleased to see that she will be our primary contact on this proposed project, and look forward to an expansion of that collaboration. We will continue work with MDA to support their responses to contract possibilities with their government and commercial clients (as we have done in the past) in order to generate follow-on application projects.

Oculus, another "Visual Analytics for Safety and Security" STPG partner based in Toronto will meet with the investigators at IEEE VAST and the Visual Analytics Consortium meetings. They will provide us with software licenses for their GeoTime and ExcelVisualizer software and support from one of their R&D team members.

EmerGeo, a new collaborator based in Vancouver will interact on a regular basis with SFU researchers who will be provided with access to their technology, training materials, and emergency operations scenarios for testing. Research personnel will support their modifications to the interface design for testing and will provide input on emergency management based upon their many years of experience as emergency managers.

Federal government partners will provide ongoing communication about initiatives that are relevant to the project, e.g. interoperability efforts. New local government partners, beginning with the Emergency Program Coordinator for the City of Richmond will support our efforts to secure interviews of key personnel and observation of exercises. Through our discussion with Lance Valcour Special Advisor - Communications Interoperability at Canadian Police Research Centre and Bob Poole of the Chemical, Biological, Radiological-Nuclear, and Explosives Research and Technology Initiative British Columbia we have recently ebegun discussion with Sheldon Dickie, Coordinator of Capability-Based Planning in CRTI and Jack Pagotto, Head of Emergency Management Systems & Interoperability for Defence R&D Canada/ Centre for Security Science in Toronto. Our program of research will benefit greatly from frequent discussion with them on current and future emergency management policies and practices.

5. Benefit to Canada

Our 2007-2009 NSERC Strategic Project Grant "Visual Analytics for Safety and Security" was the first Canadian grant to declare VA as a theme. Work done on this project has had a substantial impact on Canadian industry and government entities. It led to a large follow-on project with Boeing/Aeroinfo funded by them with student interns, and through the highly successful 2007 VA Science and Application workshop in Vancouver, helped to build discussion among Canadian Safety and Security policy-makers, researchers and companies with each other and with their counterparts in the USA. The high level of subsequent investment of US and international governments in VA R&D supports our claim that this area will be a major source of benefit for companies and for end-users in government as well as the general population whose safety they protect. Thus benefits will accrue to 3 sectors:

Developers: Analytic tool development has been hampered by a lack of fundamental understanding of analytic and operational cognition and communication. Design guidelines and metrics for assessing effectiveness of interaction design for cognitive tasks such as those performed in emergeny management and command and control ought to have grounding in cognitive science. EmerGeo MDA and Oculus produce systems that are adapted for use in specific situations and for specific users. Without effective guidelines and metrics for measuring goals of analysis such as better insights into situations, better prediction of future outcomes, and better approaches to optimizing those outcomes through human intervention, development is blind. Our research addresses this need, and in so doing build the basis for a stronger ICT industry in this important growth area. The new approaches we provide through our interaction methods and graphical visualization efforts may directly lead to IP that can be commercialized by industry partners, and will certainly inform the development of their products.

Within this sector our work will benefit SMART, SMT and Solace Systems through an increased understanding of ways in which their current products might be utilized to encorporate VA and how their R&D efforts might be shaped to provide them a competitive advantage as demand for VA systems grows. Our work thus supports their ability to coordinate their R&D efforts with both current market demand and with emerging markets that will be driven by the move to visual analytics methods.

Emergency Managers and Responders: Because of our integration of multiple tools in our research effort, end-user collaborators will gain through a better understanding of the capabilities and use of currently available and in-development VA tools (from our labs and international collaborators) at the same time they influence their development through their feedback to our field research staff. Grounded theory analyses of interviews, etc., with their analysts will give these collaborators insight into their own practices and how they may be adapted to make better use of innovations in ICT. Comparing performance cross-application will provide metrics for evaluation of current technology-enabled analytic processes and new ideas for improving analytic practices from other users and situations. "Pair analysis" sessions may well provide analytic insights directly, and will have major impacts through the better understanding of analytic cognition and communication.

General public: While the goals of NSERC's Strategic Partnership Program focuses on benefits to industry, the Safety and Security theme carries with it implications for the impact of the proposed research on the safety and security of Canada and its allies. Our choice of application areas address understanding risk and vulnerabilities for emergencies, whether caused by terrorism or natural disasters, and related areas of crime and public health (e.g. pandemic surveillance and response). Through our partnership with MacDonald Dettwiler, Solace Systems, and DRDC, these technologies and approaches will likey also find applications in reducing risk for Canadian troops and supporting the success of their missions.

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