# Laboratory for Information Globalization and Harmonization Technologies: A New Research Initiative

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**November 2001**

## Summary

The convergence of three distinct but interconnected trends – *unrelenting globalization, growing worldwide electronic connectivity, and increasing knowledge intensity of economic activity* – is creating powerful new opportunities and challenges for global politics. This rapidly changing environment has information demands that surpass existing capabilities for information access, interpretation, and overall use, thus hindering our abilities to address emergent and complex global challenges, such as *terrorism and other security threats*. This reality has serious implications for ***two diverse domains of scholarship: international relations (IR) in political science and information technology (IT).*** *Unless IT advances remain 'one step ahead' of emergent realities and complexities, strategies for better understanding and responding to critical global challenges will be severely impeded.* For example, more so now than ever, the U.S. Office of Counter-Terrorism and the newly-created Office of Homeland Security rely on intelligence information from all over the world to develop strategic responses to security threats. However, relevant information is stored in various regions throughout the world and by diverse agencies in different media, formats, and contexts. Intelligent integration of information is fundamental to developing policies to anticipate and strengthen protection against terrorist threats or attacks in the United States.

This Project's activities, and relationships with its collaborators, will be coordinated through a newly formed joint **Laboratory for Information Globalization and Harmonization Technologies (LIGHT)**. LIGHT will address information needs in the IR domain, focusing on the conflict realm, which deals with emergent risks, threats, and uncertainties of potentially global scale and scope related to: (a) crises, (b) conflicts and war; and (c) anticipation, monitoring and early warning. The goals of this initiative are to: (1) improve understanding of the types of *IR* ***information needs*** for decision making and institutional performance ***under varying degrees of risk and uncertainty***; (2) design and implement the ***System for Harmonized Information Processing,*** to facilitate access to and correct interpretation of essential information that is critical to policy and research in the IR realm, as well as to other similarly complex domains, and (3) advance developments in the use of ***information technologies*** to facilitate such interdisciplinary research and to contribute to ***new education approaches,*** tools, and methods.

Increasingly, addressing problems central to national and global interests in complex domains such as IR requires the use of technologies that easily combine observations from ***disparate sources, using different interpretations***, for different purposes, and by a wide range of users. Critical advances in IT capabilities must span multiple domains (e.g., economic, political, geographic, commercial, and demographic), diverse contexts (i.e., meanings, languages, assumptions), and a multiplicity of contending agents (i.e., states, governments, corporations, international institutions). The technology-related research will focus on acquiring and enhancing information to serve user requirements both over individual

domains (i.e., a single shared ontology) and across multiple domains, which are necessary for addressing complex challenges. The core innovation is reflected in the notion of a **Collaborative Domain Space** (CDS), within which applications in a common domain can share, analyze, modify, and develop information. For applications that span multiple domains we provide for a **Collection of CDSs** to link shared concepts in distinct domains. Moreover, we will develop the System for Harmonized Information Processing that incorporates CDSs as a basis for knowledge representation and includes all the necessary reasoning algorithms required to support information processing over a range of heterogeneous sources and applications.

The development of the system described above ***builds upon prior work***. The political science IR work will draw on an earlier Internet-based experimental 'platform' for exploring forms of information generation, provision, and integration across multiple domains, regions, languages, and epistemologies which are relevant to complex but domain-specific applications, the **Global System for Sustainable Development** (**GSSD**). The IT component builds on work on the **Context Interchange project** (**COIN**) focused on the integration of a range of distributed heterogeneous information sources (e.g., financial, supply chain, disaster relief) using ontologies, databases, context mediation algorithms, and wrapper technologies. Both groups have considerable experience with the organization and management of large scale, international, distributed, and diverse research projects, including cross-national (e.g., China, Middle East, Europe) and institutional (private, public, national and international) agencies.

The anticipated results will apply to ***any complex domain*** with multiple entities that rely on heterogeneous distributed data to address and resolve compelling problems. This initiative is supported by a network of international collaborators from (a) scientific and research institutions, (b) business and industry, and (c) national and international agencies. Expected research products include: a software platform, IR-based knowledge repository, and diverse applications in policy, research, and education which are anticipated to ***significantly impact the way complex organizations, and society in general, understand and manage critical global challenges***.

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## Section 1. Project Overview

### 1.1 Emergent Challenges to Global Information

The convergence of three distinct but interconnected trends - unrelenting globalization, growing world-wide electronic connectivity, and increasing knowledge intensity of economic activity - is creating powerful new parameters for global politics which are reflected in critical new challenges to current modes of information access and understanding. First, the discovery and retrieval of relevant information has become a daunting task due to the sheer volume, scale, and scope of information on the Internet, its geographical dispersion, varying context, heterogeneous sources, and variable quality. Second, the opportunities presented by this transformation are shaping new demands for improved information generation, management, and analysis. Third, more specifically, the increasing diversity of Internet uses and users points to the importance of cultural and contextual dimensions of information and communication. There are significant opportunity costs associated with overlooking these challenges, potentially hindering both empirical analysis and theoretical inquiry so central to many scholarly disciplines, and their contributions to national policy. *This proposal seeks to explore new ways of addressing these challenges by capturing and enhancing the value of improved access to diverse, distributed, and disconnected sources of information. Although this effort will focus on the realm of International Relations, the results will have relevancy to the broader field of Political Science, and to most scientific endeavors that have such information needs.*

### 1.2 Relevance to Political Science Scholarship

Political science is generally understood to be the systematic study of '*who* gets *what*, *when*, and

*how*' [Las58], which translates roughly into actor (or agent), stake (goal or utility), timing, and strategy (action, behavior). In this field, the demands for information in a rapidly changing world surpass existing capabilities for information access, retrieval, organization, interpretation, and use – thus creating (a) *gaps* between needs and capabilities, (b) *lags* between the availability of information and its access for effective use in scholarly as well as policy-relevant research, and (c) *barriers* to effective use created by disconnects across format, sources, language, cultural differences, and contextual conditions. International relations (IR), a sub-field of political science, focuses on the international domain, and examines issues such as sovereignty, security, cross-border conflicts, and modes of cooperation. The gaps, lags, and barriers described above are especially pertinent to theoretically- driven and empirically-informed inquiries in the IR field.

### 1.2.1 International Relations (IR) Examples

This project will focus on information needs in the conflict realm of international relations, involving emergent risks, threats of varying intensity, and uncertainties of potentially global scale and scope. Specifically, we propose to focus on: (a) crisis situations; (b) conflicts and war; and (c) anticipation, monitoring, and early warning. Information needs for research in these domains are extensive, and vary depending on: (1) the *salience* of information (i.e. the criticality of the issue), (2) the *extent of customization*, and (3) the *complexity* at hand. More specifically, in:

- **Crisis situations:** the needs are characteristically immediate, usually highly customized, and generally require complex analysis, integration, and manipulation of information. International crises are now impinging more directly than ever before on national security, thus rendering the information needs and requirements even more pressing.
- **Conflicts and War**: the needs are not necessarily time-critical, are customized to a certain relevant extent, and involve a multifaceted examination of information. Increasingly, it appears that coordination of information access and analysis across a diverse set of players (or institutions) with differing needs and requirements (perhaps even mandates) is more the rule rather than the exception in cases of conflict and war.
- **Anticipation, Monitoring and Early Warning**: the needs tend to be gradual, involve routinized searches, and require a relatively straightforward extraction of information from sources that may evolve and change over time. However, in today's global context, 'preventative action' may even take on new urgency, and create new demands for information services.

The examples in Table 1 illustrate the types of information needs required for effective research, education, decision-making, and policy analysis on a range of conflict issues for which there is considerable scholarship in place. These issues remain central to matters of security in this increasingly globalized world.

| Illustrative Cases | Example of Information Needs | Intended Use of Information |
|---|---|---|
| **1. Strategic Requirements for Managing Cross-Border Pressures in a *Crisis***<br>The UNHCR needs to respond to an exodus of large numbers of Afghans into neighboring countries, triggered by an outbreak of war in Afghanistan. | Logistical and infrastructure information for setting up refugee camps, such as potential sites, sanitation, and potable water supplies. | Facilitated coordination of relief agencies by providing up-to-date information during a crisis for more rapid response (as close to real time as possible). |

| Illustrative Cases | Example of Information Needs | Intended Use of Information |
|---|---|---|
| **2. Capabilities for Management during an Ongoing *Conflict & War*** The goal of the newly established UNEP-Balkans group is to assess whether the ongoing Balkan conflict has had significant environmental and economic impacts on the region. The data, extensive as it may be, is dispersed and presented in different contexts. | Environmental and economic data on the region prior to the initiation/ escalation of the conflict. Comparison of this data with newly collected data to assess the impacts to environmental and economic viability. | Improved decision making during conflicts and war - taking into account contending views and changing strategic conditions - in order to better prepare for, and manage, future developments and modes of resolution. |
| **3. Strategic Response to Security Threats for *Anticipation, Prevention, and Early Warning*** The Office of Counter-Terrorism and newly-created Office of Homeland Security coordinate all U.S. government cooperation efforts with foreign governments. Relevant information is in different regions of the world, posing language and cultural barriers. | Intelligence data from foreign governments, non-governmental agencies, US agencies, and leading opinion leaders worldwide. | Streamline potentially conflicting information in order to facilitate coherent anticipation, preventive monitoring, and early warning. |

**Table 1. Illustrating Information Needs in Three Contexts**

## 1.3 Information Needs in the Conflict Realm

### 1.3.1 Operational Example

For illustrative purposes only, this section elaborates on the *gaps, lags*, and *barriers*, described above, which are prevalent in the types of examples illustrated by Example 2 in Table 1. The specific question is: **to what extent have economic performance and environmental conditions in Yugoslavia affected the conflicts in the region?** The relevance of this question lies in that it is likely to shape policy priorities for different national and international institutions, as well as reconstruction strategies, and may even determine which agencies will be the leading players in the post-war period. Moreover, there are potentials for resumed violence and the region's relevance to overall European stability remains central to the US national interest. This is not an isolated case, by any means, but one that illustrates concurrent challenges for information compilation, analysis, and interpretation.

For example, if we are interested in determining the change of carbon dioxide ($CO_2$) emissions in the region, normalized against the change in GDP - before and after the breakout of the war – we need to take into account territorial and jurisdictional boundaries, changes in accounting and recording norms, and varying degrees of autonomy. User requirements add another layer of complexity. For example, what units of $CO_2$ emissions and GDP should be displayed, and what unit conversions need to be made from the information sources? Which Yugoslavia is of concern to the user- the country defined by its current borders, or the entire geographic area formerly known as Yugoslavia? One of the effects of the war is that the region, which used to be one country consisting of six republics and two provinces, has subsequently been reconstituted into five legal entities (countries), each having its own reporting formats, currency, units of measure, and new socio-economic parameters. In other words, the meaning of the request for information will differ, depending on the *actors*, *actions, stakes* and *strategies* involved.

In this simple case, we suppose that the request comes from a reconstruction agency interested in finding the following values: $CO_2$ emissions (in tons/yr), $CO_2$ per capita, annual GDP (in million USD/yr), GDP per capita, and the ratio $CO_2$/GDP (in tons $CO_2$/million USD) for the entire region of the former Yugoslavia (see the alternative User 2 scenario in Table 2). A restatement of the question would then become: **what is the change in $CO_2$ emissions and GDP in the region formerly known as Yugoslavia before and after the war?**

This question relies on diverse sources for observations over time on armed conflicts, economic performance, and environmental degradation. By necessity, one needs to draw data from diverse types of sources (we call these differing *domains* of information) - such as, economic data (e.g., the World Bank,

UN Statistics Division), environmental data (e.g., Oak Ridge National Laboratory, World Resources Institute), and country history data (e.g., the CIA Factbook). Merely combining the numbers from the various sources is likely to produce serious errors due to different sets of assumptions driving the representation of the information in the sources These assumptions are often not explicit but are an important representation of 'reality' (we call these the meaning or *context* of the information, which will be explained in more detail in Section 3.)

<table>
<tr><th>Domain and Sources Consulted</th><th>Sample Data Available</th><th>Basic Question, Information User Type & Usage</th></tr>
<tr><td>Economic Performance<br>• World Bank's World Development Indicators database<br>• UN Statistics Division's database<br>• Statistics Bureaus of individual counties</td><td>A. Annual GDP and Population Data:<br><table><tr><th>Country</th><th>T0.GDP</th><th>T0.Pop</th><th>T1.GDP</th><th>T1.Pop</th></tr><tr><td>YUG</td><td>698.3</td><td>23.7</td><td>1627.8</td><td>10.6</td></tr><tr><td>BIH</td><td></td><td></td><td>13.6</td><td>3.9</td></tr><tr><td>HRV</td><td></td><td></td><td>266.9</td><td>4.5</td></tr><tr><td>MKD</td><td></td><td></td><td>608.7</td><td>2.0</td></tr><tr><td>SVN</td><td></td><td></td><td>7162</td><td>2.0</td></tr></table>- GDP in billions local currency per year<br>- Population in millions</td><td rowspan="4">Question:<br>How did economic output and environmental conditions change in YUG over time?<br><br>User 1: YUG as a geographic region bounded at T0:<br><table><tr><td>Parameter</td><td>T0</td><td>T1</td></tr><tr><td>$CO_2$</td><td>35604</td><td>29523</td></tr><tr><td>$CO_2$/capita</td><td>1.50</td><td>1.28</td></tr><tr><td>GDP</td><td>66.5</td><td>104.8</td></tr><tr><td>GDP/capita</td><td>2.8</td><td>4.56</td></tr><tr><td>$CO_2$/GDP</td><td>535</td><td>282</td></tr></table><br>User 2: YUG as a legal, autonomous state<br><table><tr><td>Parameter</td><td>T0</td><td>T1</td></tr><tr><td>$CO_2$</td><td>35604</td><td>15480</td></tr><tr><td>$CO_2$/capita</td><td>1.50</td><td>1.46</td></tr><tr><td>GDP</td><td>66.5</td><td>24.2</td></tr><tr><td>GDP/capita</td><td>2.8</td><td>1.1</td></tr><tr><td>$CO_2$/GDP</td><td>535</td><td>640</td></tr></table><br>Note:<br><br>T0: 1990 (sampled prior to breakup)<br>T1: 2000 (sampled after breakup)<br>$CO_2$: 1000's tons per year<br>$CO_2$/capita: tons per person<br>GDP: billions USD per year<br>GDP/capita: 1000's USD per person<br>$CO_2$/GDP: tons per million USD</td></tr>
<tr><td>Environmental Impacts<br>• Oak Ridge National Laboratory's CDIAC database<br>• WRI database<br>• GSSD<br>• EPA of individual countries</td><td>B. Emissions Data:<br><table><tr><th>Country</th><th>T0</th><th>T1</th></tr><tr><td>YUG</td><td>35604</td><td>15480</td></tr><tr><td>BIH</td><td></td><td>1279</td></tr><tr><td>HRV</td><td></td><td>5405</td></tr><tr><td>MKD</td><td></td><td>3378</td></tr><tr><td>SVN</td><td></td><td>3981</td></tr></table>- Emissions in 1000s tons per year</td></tr>
<tr><td>Country History:<br>• CIA<br>• GSSD</td><td>T0.{YUG} = T1.{YUG, BIH, HRV, MKD, SVN}<br>(i.e., geographically, YUG at T0 is equivalent to YUG+BIH+HRV+MKD+SVN at T1)</td></tr>
<tr><td>Mappings Defined:<br>• Country code<br>• Currency code<br>• Historical exchange rates*<br><br>* Note: Hyperinflation in YUG resulted in establishment of a new currency unit in June 1993. Therefore, T1.YUN is completely different from T0.YUN.</td><td><table><tr><th>Country</th><th>Code</th><th>Currency</th><th>Currency Code</th></tr><tr><td>Yugoslavia</td><td>YUG</td><td>New Yugoslavian Dinar</td><td>YUN</td></tr><tr><td>Bosnia and Herzegovia</td><td>BIH</td><td>Marka</td><td>BAM</td></tr><tr><td>Croatia</td><td>HRV</td><td>Kuna</td><td>HRK</td></tr><tr><td>Macedonia</td><td>MKD</td><td>Denar</td><td>MKD</td></tr><tr><td>Slovenia</td><td>SVN</td><td>Tolar</td><td>SIT</td></tr></table><br><table><tr><th>C_From</th><th>C_To</th><th>T0</th><th>T1</th></tr><tr><td>USD</td><td>YUN</td><td>10.5</td><td>67.267</td></tr><tr><td>USD</td><td>BAM</td><td></td><td>2.086</td></tr><tr><td>USD</td><td>HRK</td><td></td><td>8.089</td></tr><tr><td>USD</td><td>MKD</td><td></td><td>64.757</td></tr><tr><td>USD</td><td>SIT</td><td></td><td>225.93</td></tr></table></td></tr>
</table>

**Table 2. Operational Example: Information Needs in Cases of Conflict**

The purpose of Table 2 is to illustrate some of the complexities in a seemingly simple question. In addition to variations in data sources and domains, there are significant differences in contexts and formats, critical temporality issues, and data conversions that all factor into the user's information needs.

As specified in the table, time T0 refers to a date b*efore the war* (e.g., 1990), when the entire region was a single country (referred to as "YUG"). Time T1 refers to a date a*fter the war* (e.g., 2000), when the country "YUG" retains its name, but has lost four of its provinces, which are now independent countries. The first column of Table 2 lists some of the sources and domains covered by this question. The second column shows sample data that could be extracted from the sources. The bottom row of this table lists auxiliary mapping information that is needed to understand the meanings of symbols used in the other data sources. For example, when the GDP for Yugoslavia is written in YUN units, a currency code source is needed to understand that this symbol represents the Yugoslavian Dinar. The third column lists the outputs and units requested by the user. Accordingly, for User 1, a simple calculation based on data from country "YUG" will invariably give a wrong answer. For example, deriving the $CO_2$/GDP ratio by simply summing up the $CO_2$ emissions and dividing it by the sum of GDP from sources A and B will not provide a correct answer. The proper calculation involves numerous steps, including selecting necessary sources, making appropriate conversions, and using correct calculations. For example:

For time T0:

1. Get $CO_2$ emissions data for "YUG" from source B;
2. Convert it to tons/year using scale factor 1000;call the result X;
3. Get GDP data from source A;
4. Convert to USD by looking up currency conversion table, an auxiliary source; call the result Y;
5. No need to convert the scale for GDP because the receiver uses the same scale, namely, 1,000,000;
6. Compute X/Y (equal to 535 tons/million USD in Table 2).

For time T1:

1. Consult source for country history and find all countries in the area of former YUG;
2. Get $CO_2$ emissions data for "YUG" from source B (or a new source);
3. Convert it to tons/year using scale factor 1000; call the result X1;
4. Get $CO_2$ emissions data for "BIH" from source B (or a new source);
5. Convert it to tons/year using scale factor 1000; call the result X2;
6. Continue this process for the rest of the sources to get the emissions data for the rest of the countries;
7. Sum X1, X2, X3, etc. and call it X;
8. Get GDP for "YUG" from source A (or alternative); Convert it to USD using the auxiliary sources;
9. No need to convert the scale factor; call the result Y1;
10. Get GDP for "BIH" from source E; Convert it to USD using the auxiliary sources; call the result Y2;
11. Continue this process for the rest of the sources to get the GDP data for the rest of the countries;
12. Sum Y1, Y2, Y3, etc. and call it Y;
13. Compute X/Y (equal to 282 tons/million USD in Table 2).

The complexity of this task would be easily magnified if, for example, the $CO_2$ emissions data from the various sources were all in different units or, alternatively, if demographic variables were drawn from different institutional contexts (e.g., with or without counting refugees). This example shows some of the operational challenges if a user were to manually attempt to answer this question. Since this case highlights some common data difficulties in the IR domain, it helps to clarify the potential contributions of information technology tools for theory, methods, policy, and practice in the field. One goal of this effort is to create a system that can automatically determine and reliably perform the steps shown above in response to a user's request.

### 1.3.2 Current IR Practices

Currently, IR theory isolates behaviors of agents (states, firms, etc.) from their environmental context (i.e., by separating social and natural systems). As a result, there is little theoretical guidance for modes of interface between activities and environments, and only nominal practice in integrating information on incidences of conflict with environmental data. This is a case where actual practice has preceded theory and analysis. For example, leading IR scholars on causes and consequences of war (notably [Van99]) ignore 'environment' factors entirely, and only recently have leading historians

addressed potential interconnections [McN00]. Barriers to information access and interface, shown above, will hamper efforts to draw effectively upon indices of natural systems and social systems, and impede serious efforts to develop more integrated perspectives on the matter of actors, actions, and outcomes, particularly in cases where conflict and violence create interdependent social and environmental dislocations.

## 1. 4 Project Objectives

The Project seeks to undertake novel research with substantial impacts on a wide range of domains transcending political science. Our purpose is to produce useful tools and a broad architecture that can be applied to many scholarly disciplines, by focusing on information needs that are strategically compelling, emerge from complex domains, require cross-disciplinary connectivity and linkages, and involve a diversity of actors and agents, distributed data sources, and forms of provision. Specifically, the goal is to generate advances in information technology to help support and enhance empirical research and theoretical inquiry in the study of international relations by (1) *identifying barriers to access and analysis of critical information* for enhancing the value of empirical and theoretical studies in this domain of political science, (2) *conducting basic research on effective information technologies* for analysis of behaviors in similarly complex domains, where there are multiple actors, jurisdictions, institutions, and domains of salience, and (3) advancing developments in the *use of information-based technologies* to facilitate *interdisciplinary research* and to contribute to *new education approaches* and tools.

## 1.5 Existing Foundations – GSSD and COIN

Important research in two areas has already been completed that provides important foundations for addressing the emergent challenges discussed in Table 1: the *Global System for Sustainable Development* (GSSD, see gssd.mit.edu) and the *COntext INterchange* Project (COIN, see context2.mit.edu).

### 1.5.1 GSSD as a "Platform"

The *Global System for Sustainable Development* serves as an Internet-based platform for exploring forms of information access, provision, and integration across multiple information sources, languages, cultural contexts, and ontologies. GSSD has an extensive, quality-controlled set of ontologies related to system sustainability, which is relevant to the field of international relations. In addition, GSSD has made considerable gains into understanding the organization and management of large scale, distributed, and diverse research teams, including cross-national (China and Japan, and countries in the Middle East and Europe) and institutional partners (private, public, and international agencies). Designed and implemented by social scientists, GSSD is seen as demonstrating 'opportunities for collaboration and new technologies,' according to the National Academy of Engineering [RAC01, p. viii].

The conceptual framework for GSSD serves to provide linkages across multiple domains and levels of activity that are relevant to the broader notion of sustainability. GSSD databases cover issues related to dynamics of conflict, as well as other domains relevant to our proposed research, such as migration, refugees, unmet human needs, as well as evolving efforts at coordinated international actions.

While GSSD provides a rich testing ground for the new information technologies we propose to develop (described in Section 3), we recognize that some key limitations in its information streamlining and analysis capabilities include: absence of automated methods for information aggregation from various sources, dearth of context mediation capabilities, lack of customized information retrieval capabilities, and need for further development of ontology representations. Effective resolution of such limitations constitutes an important research challenge and will be an important outcome of this endeavor.

### 1.5.2 COIN

The *COntext INterchange* (COIN) Project has developed a basic theory, architecture, and software prototype for supporting intelligent information integration employing context mediation technology [MAD99, GBM*99, GoBM96, Goh96, SM91a]. We propose to utilize the foundation of COIN to develop theories, methodologies, and a System for Harmonized Information Processing. The fundamental concept underlying such a system is the representation of knowledge as **Collaborative Domain Spaces (CDSs)**. A **CDS** is a grouping of the knowledge including source schemas, data context, conversion functions, and source capabilities as related to a single domain ontology. The software components needed to provide harmonized information processing (i.e. through the use of a CDS or collections of CDSs) include a context mediation engine [BGL*00, Goh96], one or more ontology library systems, a context domain and conversion function management system, and a query execution and planner [Fynn97]. In addition, support tools are required to allow for applications' (i.e. receivers') context definition and source definitions to be added and removed (i.e., schemas, contexts, capabilities). Developing a flexible, scalable software platform will require the combination of existing COIN research and significant additional research in a number of key research areas as described in Section 3.4.

## 1.6. Research Team

Due to the highly multi-disciplinary nature of this project, we have composed a research team that is uniquely qualified to conduct this work. The PIs of this project come from MIT's School of Humanities, Arts, and Social Sciences (Choucri), School of Engineering (Madnick), and School of Management (Siegel and Madnick), and the students who will contribute significantly to this research come from all these diverse Schools. Furthermore, the PIs have extensive prior research experience in the critical areas necessary to accomplish the goals of this project.

## 1.7. Proposal Organization

The remainder of this proposal will elaborate on the intended research tasks. Section 2 will illustrate research needs in International Relations, and how these needs can directly benefit from the information technologies described in Section 3. Section 4 provides a brief description of the new laboratory that will ensure coherence among the components of the project and also handle outreach activities. Finally Sections 5 and 6 will present the anticipated contributions of the project, with a focus on educational impacts.

# Section 2. Domains of Political Inquiry

## 2.1 Brief Domain Overview

The study of International Relations (IR) in Political Science generally converges around two seemingly distinct, but interrelated 'poles', namely matters of (a) conflict and war and (b) cooperation and collaboration. Both 'poles' address implications of sovereignty and security, national action and international consequences – among others. Differences in theories, methods, and data practices create different perspectives on issues, shaping different "questions", and potentially leading to different "answers". And the proliferation of new actors (i.e. states, non-governmental organizations, cross-border political groups, international institutions, global firms, etc.) creates new sources of data and new difficulties for access and management. Therefore, it comes as no surprise that fundamental changes in the international system have created new challenges for research and policy.

### 2.1.1 International Changes

The fall of the Berlin Wall, the end of Communism as a global threat, the demise of the Soviet

Union, and the creation of new states with new configurations and strategic dilemmas are among the most significant and observable of these changes. And while there is a near-consensus that globalization is an increasingly salient phenomenon, there is less agreement as to its nature, scale, and scope and, more importantly, the extent to which it alters prevailing patterns of 'politics as usual'. By the same token, new realities such as these have facilitated new venues for collaboration on a range of relatively 'new' issues, notably environmental degradation, electronic communication, regulatory strategies, etc.

It is not our purpose here to provide a review of the IR field and the underlying theoretical contentions, but rather to touch base with those aspects upon which we build our own research proposal, and to focus on the theoretical and empirical issues to which we expect to make some direct contributions. Our point of departure is reflected by a review of empirical challenges in a recent issue of *International Political Science Review* (2001), devoted to "Transformation of International Relations – Between Change and Continuity". It argues that the "reconfiguration of the founding concepts of international relations ... is linked to important paradigmatic changes" [Sind01, p. 224] and that state-centric modes of analysis and information configuration must be augmented by methods that help capture changes in both structure and process in the international arena.

### 2.1.2 Opportunity Cost

Under these circumstances, it is somewhat intriguing that the political science field as a whole has paid relatively little attention to the Internet and the forging of 'cyberspace', which has literally created a new domain of IR, known as 'cyberpolitics'. It is rather revealing that the *Annual Review of Political Science,* one of the profession's leading and most respected publications, has made little reference, if any, to the reality of the Internet, to the emergence of 'cyberpolitics', and to potentially important contributions of information technology to the study of IR. (Neither the 1999 nor the 2000 *Annual Reviews* address any aspect of this new information-political science interface, nor are there even indirect references to such potentials). This is especially surprising given the strong and growing traditions of quantitative political analysis in many domains of political science. Interestingly, the *International Political Science Review* (2000) issue "CyberPolitics in International Relations" [Cho00] identifies new directions of research, research priorities, and critical next steps. But the profession's leading journal, the *American Political Science Review*, has yet to address these new domains, or to recognize attendant research challenges. This is of some irony, of course, since the United States is the world leader in information technologies, and US political scientists continue to shape the field of IR.

While the provision of information through the Internet has become standard operating procedure in almost all endeavors in both the scholarly and the policy domains, there are significant opportunity costs associated with barriers to the effective use of dispersed, diverse, and disconnected data sources. *Our goal is to reduce prevailing barriers, enhance understanding and meaning across substance, topics, and ontologies, and to provide new tools for IR research.*

### 2.1.3 Logic for Proposed Research

This goal is important because existing information systems are not easily comparable, nor do they readily interface. For example, there are data on incidences of conflict between nations located on the web sites of a wide range of institutions with different capabilities and objectives – such as the US Department of State, SIPRI (the Swedish institution focusing on peace research), the UN Higher Commission on Refugees, and the Correlates of War Project, to name a few. So, what is the 'real' incidence of conflict and the 'real' volume of casualties – at one point in time, over time, and as the contenders change and reconfigure their own jurisdictions? These are typical questions that have plagued researchers in the IR field, as far back as 1942, with classics in the field such as Quincy Wright's *A Study of War,* [Wri65] and even earlier, with Lewis Fry Richardson's *Statistics of Deadly Quarrels* (1917) [Rich60].

In order to (a) bound and define more precisely the proposed research strategy and (b) focus on

its operational as well as analytical implications, we turn to the proposition at the onset of this proposal, namely that important research challenges are defined by the *new convergences* (i.e. globalization, world-wide connectivity, knowledge intensity) that shape *new information challenges* (i.e. information upsurge, new needs due to changes in content and contexts, etc.) noted in the opening section of this proposal. These challenges are evident across the two 'polar' aspects in the study of IR, namely *conflict and violence* and *cooperation and coordination.* We fully recognize that these two domains are extensive in scale and scope, differ in their theoretical underpinnings, and are not mutually exclusive in their content or coverage. Considerable advances in the field enable us to define specific gaps and needs that can be addressed rigorously by designing a cross-disciplinary and replicable research strategy. Here we focus largely on the conflict domain and concentrate on three modal types: (i) crises dynamics, (ii) conflict and war, and (iii) anticipation, preventative, and early warning. Most of the challenges we will address are also relevant to the collaboration domain, such as, modes of coordinated international action, approaches to peace-making, alignment of national and international responses (toward shared goals), and private sector cooperation (promoted by projects such as the Global Reporting Initiative (GRI)).

## 2.2 IR Research Needs

The proposed research strategy is framed by (1) *central tendencies* in the field and (2) *information gaps impeding theory development.*

### 2.2.1 Central Tendencies

While there exists no 'single authoritative view' of the field as a whole, Katzenstien, Keohane, and Krasner, eds. [KKK99], summarize two dominant perspectives in the field (labeled as rationalist and constructivist), both of relevance to conflict and cooperation. Their book is noteworthy for stressing differences as well as similarities across the two perspectives, but it is rather limited in its attention to quantitative data and information. For example, the chapter by Milner [Miln99], which assumes that states are the main actors in international relations, would have benefited from data on state formation and demise over time, comparisons with emergence of non-state actors, and a net assessment of the implications. In the absence of agreed upon metrics to track fundamental structural changes, IR theory remains dominated by assertions about, rather than, metrics of, change. In the segment of the field known as Quantitative International Politics (QIP), theory development is generally more data-driven and thus more vulnerable to the information limitations than other studies. Earlier QIP works, such as Hoole and Zinnes [HZ76] and Russett [Russ72], as well as the more recent advances by Levy [Levy89], Pollins and Schweller [SP99], and Choucri and North [ChoN93], illustrate the general progression in the field and the persistent data problems. Concurrently, [Alk96] highlighted some of the fundamental challenges to humanistic approaches to international studies, notably uses of computer-assisted applications.

In a related set of developments, some scholars in the field have given serious attention to interconnections between 'theory' and 'quantitative analysis' [Rose90]. Especially illustrative in this connection is the issue of *International Studies Quarterly* [CR96] devoted to evolutionary perspectives in international relations. Leading scholars such as George Modelski, Robert Gilpin, Cioffi-Revilla, and others, have begun to articulate the importance of transformation and adaptation over time, in contrast to the common focus on discrete events, or retrospective interpretation, which is quite dominant in the field. However, cumbersomeness in information access and data analysis makes it very difficult to replicate these works or to extend them in cumulative directions.

### 2.2.2 Impacts of Information Practices

There is a critical dilemma for researchers whose theoretical work relies on the use of systematic information and robust databases. Despite the *abundance* of existing data and information, there is a *paucity* in the consistency, reliability, and connectivity of the information. For example, in the conflict

theory domain, the long tradition of tracking wars and casualties has been severely hampered by the difficulties of generating an integrated information system, drawing upon large scale efforts in the profession undertaken by a large number of different research groups. The same point holds for the cooperation theory domain where, for example, efforts to measure 'regime formation' and 'compliance' in a wide range of specific issue-areas are hampered by the diversity of ontologies, data meanings, and metrics. This dilemma common to both studies in IR is a *data and information disconnect* that appears at first glance to stem from data paucity, but is actually due to the inability to fully utilize the data compiled by different scholars on the same issue-areas.

Addressing the information disconnects will enable more intelligent access to existing databases and help to bridge the gap between conventional statistical analysis in the field and innovative modeling efforts to represent complexity in IR. For example, in the conflict domain, this will help us articulate and test propositions about potential linkages among long term pressures leading to antagonisms, the formation of escalation processes, the 'outbreak' of critical crises, and possibly the 'war' event as a distinctive outcome. In the cooperation domain, this would enable us to test for content and effectiveness of regimes by type, commitment, and potentials for durability, and across different issues, ranging from international treaties on environmental management to the non-proliferation of nuclear weapons.

## 2.3 Research Priorities

Our expectation is that advances in integrating critical pieces of information will allow the *whole* to yield insights and evidence greater than the sum of the *individual* parts. We seek to focus on applications of advanced information tools in order to reduce barriers to cumulativeness, and correct distortions due to data temporality

### 2.3.1 Reducing Barriers to Cumulativeness

In the social sciences, 'cumulativeness' refers to the extent to which advances in knowledge are based on previous findings, and the extent to which the linkages among them can be made explicit. We seek to understand exactly what findings derive from which theories and are shaped by what types of empirical data. Currently, advances in the field are difficult due to the lack of reliable ways to make appropriate inferences based on previous work. This difficulty stems from the differences in assumptions and theoretical perspectives and the inability to draw inferences *across* data sets about the *same* common phenomena. Efforts as those by Geller and Singer [GS97] in the domain of international conflict are laudable indeed, but have serious limitations in coverage and approach, leading to somewhat arbitrary conclusions due largely to selective review rather than comprehensive assessment of existing studies. Such limitations would be reduced substantially if there were greater ease of access to data and information from the very studies under review. Chronic difficulties in the field, such as these, seriously obstruct cross-method, cross-data, and cross-ontology comparisons. By the same token, one of the field's most innovative approaches to analysis of international conflicts (CASCON [BM97], see web.mit.edu/cascon/) is limited by constraints in cross-case comparisons and the difficulties of customizing information integration from multiple sources. Since CASCON is used in both the scholarly and the policy communities, reducing its current constraints will enhance its usefulness. In short, improving effective information access will increase propensities for cumulativeness in the field, in theoretical as well as empirical terms.

### 2.3.2 Correcting Distortions due to Data Temporality

We seek to understand the principles underlying initial compilation of data and their potential shifts over time, also referred to as the temporality of information. This is particularly relevant to certain issues within IR such as state integration and disintegration, alliance formation and dissolution, and cross-border activities and transnationalism. These issues blur the distinction between national politics and IR,

and remind us that sources of insecurity can come from either of these domains, or both. For example, Walter and Snyder [WS99] point to critical features of local and civil wars that may generate international and global implications. This blurring of system boundaries between internal and external politics has important implications for information organization, management, analysis, and distribution; and these are likely to change over time. Given that the dominant practice has been to assume some form of unit stability (state boundaries, jurisdictions, etc.), it remains operationally very cumbersome to rescale or readjust observations given changes in boundaries, for example, and the attendant institutional responsibilities for national statistics. In addition, it is not uncommon for definitions of core terms to change, in response to changes in emerging 'realities', but our information practices continue to lag in this regard. For example, changes in the meanings of terms such as 'citizens' (that defines the national population), taxes (that shape revenue sources), and boundaries (that determine jurisdictional responsibility) could potentially affect the way in which information is organized and the inferences that can be drawn.

### 2.3.3 Reminder of Operational Example

In Section 1 above, we pointed to an operational example– identifying select consequences of the war in the Balkans– and pointed to some of the necessary steps that must be undertaken in order to yield 'correct' answers to questions posed by different 'users'. Stylistic as it might seem, this example is fundamental as it highlights matters of changing boundaries, sovereignties, currencies, etc. that are critical to the very definition and determination of 'who gets what, when, and how' in the international domain. The research priorities defined above will shape our *research platform* and specific *research tasks* (with attendant goals and potential contributions).

## 2.4 Research Platform

As noted earlier, we frame our proposed work in the context of the GSSD knowledge-network. The *information base* for the GSSD 'laboratory' consists of web based resources from over 250 institutions worldwide, representing a diverse set of data by type, scale and scope that is then cross-referenced and cross-indexed for ease of retrieval and analysis, according to an integrated and coherent conceptual framework covering the knowledge domain. The domain consists of a hierarchical and nested representation spanning 14 key socio-economic 'sectors' of human activities, known problems, scientific and technological responses, social and regulatory instruments, and modes of resolution. GSSD is chosen as a research platform because it: (1) provides a *domain ontology* based on rigorous applications of social science theories, and related domains in science and technology, (2) offers practical reasoning rules for forming additional ontologies, (3) presents scenarios for broad applications of the integrated technologies to be developed in this project, and (4) has identified a large and important set of information sources.

## 2.5 Research Tasks and Expected Contributions

**1. Undertake a comprehensive information-base survey.** The goal of this task will be to fully understand attributes of the data types in the GSSD knowledge base that are relevant to conflict. The anticipated contributions of this phase include: (a) **an assessment of** data types within the *conflict* domain, according to the following attributes: data source, format, organization, temporality attributes, provision rules, and utility for user-driven query.

**2. Conduct an extensive multi-disciplinary and distributed user survey and develop test cases.** The goal of this task will be to develop and apply methods to survey current and future information demands from diverse IR actors, as differentiated by (a) data users; (b) data providers, and (c) data intermediaries. Case studies that represent different user types and data needs will emerge from this assessment. The anticipated deliverables of this phase include: (a) a **multi-dimensional assessment of information demand** from different user types within the conflict domains discussed earlier, based on

surveys, workshops, and in-depth interviews, and (b) a set of **IR test cases**, developed based on the information-base and user surveys, illustrating information gaps, lags and barriers in the field, for application of the newly developed technologies to IR theories and methods.

**3. Refine and develop ontologies and a knowledge repository to represent IR domains and provide a test bed for the new technologies.** The goal of this task will be to refine the GSSD ontology and develop any other ontologies that are necessary to support the specific IR subject-domains used as the testing ground for the proposed technologies. The anticipated contributions of this phase include: (a) **new and refined ontologies** related to the conflict/IR domain and (b) a **knowledge repository** to house the ontologies and information on applicable data sources on the Internet.

**4. Define the substantive features of the new technologies for enhancing information capabilities in IR theory and methods development, and test the effectiveness of the design.** The goal of this task will be to demonstrate the technologies' domain specific and practical applications when applied to IR test cases and to explore relevance for similarly complex domains. The anticipated deliverables include: **collaborative assessments** of the technologies' effectiveness to address IR information issues and the architecture's capacity for scalability and cross-domain applicability, based on the following criteria: support for diverse information needs in a complex domain, as the salience, extent of customization, and complexity of the data demands vary, and robustness to changes in information properties and demands, given the diverse knowledge providers and the emerging global challenges and uncertainty in this increasingly complex world.

**5. Enrich curriculum design and development**. The goal of this task will be to promote educational development by incorporating the technologies developed in this project into (i) political science and other social science curricula; and (ii) multidisciplinary courses with strong international components. The anticipated deliverables of this phase include: (a) **on-line courses** on conflict and war, drawing on the ontologies developed in Task 3 and, (b) with the help of our international collaborators, systematic tests of the **relevance of course design and implementation** in different regions of the world, in order to differentiate context specific vs. generic features of the domain(s) addressed.

## Section 3. Information Technology Research

### 3.1 Needs for Harmonized Information Processing and Collaborative Domain Spaces

Advances in computing and networking technologies now allow extensive volumes of data to be gathered, organized, and shared on an unprecedented scale and scope. Unfortunately, these newfound capabilities by themselves are only marginally useful if the information cannot be easily **extracted** and **gathered** from **disparate sources**, if the information is represented with **different interpretations**, and if it must satisfy **differing user needs** [MHR00, MAD99, CFM*01]. The data requirements (e.g., scope, timing) and the sources of the data (e.g., government, industry, global organizations) are extremely diverse. The need for intelligent harmonization of heterogeneous information is important to all information-intensive endeavors – which encompasses many disciplines including governments, education, science and engineering. The fundamental technology research to be performed has broad relevancy for all global applications, such as Manufacturing (e.g., Integrated Supply Chain Management), Transportation/Logistics (e.g., In-Transit Visibility), Government/Military (e.g., Total Asset Visibility), and Financial Services (e.g., Global Risk Management). It is proposed that the application focus for this effort be in the domain of international relations that, by definition, takes into account internal as well as external dimensions of relations among actors in both the public and the private domains.

This research effort will:

1. Analyze the data and technology requirements for the categories of problems described in Section 2;
2. Research, design, and develop extensions and improvements to the underlying theory and

components;

3. Assess and include existing off the shelf and research developed technologies as needed;
4. Provide scalable, flexible platform for servicing the range of applications described in Section 2; and
5. Demonstrate the effectiveness of the theories, tools, and methodologies through technology transfer to other collaborating organizations.

## 3.2 Illustrative Example of Information Extraction, Dissemination, and Interpretation Challenges

As an illustration of the problems created by information disparities, let us refer back to the example from the conflict realm introduced in Section 1.3.1. The challenge is how best to assess the environmental effects of armed conflict in light of variations in levels and rates of economic performance. The specific question was: **what are the impacts of $CO_2$ emissions on economic performance in warring regions.** It is necessary to draw data from diverse sources such as CIA (for current boundaries), World Resources Institute (for $C0_2$ emissions), and the World Bank (for economic data).

There are many additional information challenges that had not been explicitly noted earlier, such as:

***Information Extraction***: Some of the sources may be full relational databases, in which case there is the issue of remote access. In many other cases, the sources may be traditional HTML web sites, which are fine for viewing from a browser but not effective for combining data or performing calculations (other than manually "cut & paste"). Other sources might be tables in a text file, Word document, or even a spreadsheet. Although the increasing use of eXtensible Markup Language (XML) will reduce some of these interchange problems [MAD01], we will continue to live in a very heterogeneous world for quite a while to come.

***Information Dissemination***: The users want to use the resulting "answers" in many ways. Some will want to see the desired information displayed in their web browser but others might want the answers to be deposited into a database, spreadsheet, or application program for further processing.

***Information Interpretation***: Although the problems of information extraction and dissemination will be addressed in this research, the most difficult challenges involve information interpretation, as illustrated below.

Specifically, an example question is: "What is the change of $CO_2$ emissions per GDP in Yugoslavia before and after the Balkans war?"

*Before the war* (time T0), the entire region was one country. Data for $CO_2$ emissions was in thousands of tons/year, and GDP was in billions of Yugoslavian Dinars. *After the war* (time T1), Yugoslavia only has two of its original five provinces; the other three provinces are now four independent countries, each with its own currency. The size and population of the country, now known as Yugoslavia, has changed. Even Yugoslavia has introduced a new currency to combat hyperinflation.

From the perspective of any one agency, **UNEP** for example, the question: "How have $CO_2$ emission per GDP changed in Yugoslavia after the war?" may have multiple interpretations. Not only does each source have a context, but so does each user (also referred to as a receiver). For example, does the user mean Yugoslavia as the original geographic area (depicted as *user 1* in Table 2) or as the legal entity, which has changed size (*user 2*). To answer the question correctly, we have to use the changing context information. A simple calculation based on the "raw" data will not give the right answer. As seen earlier, the calculation will involve many steps, including selecting necessary sources, making appropriate conversions, and using correct calculations. Furthermore, each user might have a different preferred context for their answer, such as: tons/million USD or kilograms/billion EURO, etc. More of these information harmonization challenges will be highlighted in Section 3.4.

Although seemingly simple, this example addresses one of the most complex issues in IR: namely the impact of changing legal jurisdictions and sovereignties on (a) state performance, (b) salience of stress, (c) demographic shifts and (d) estimates of economic performance, as critical variables. Extending this example to the case of the former Soviet Republics, before and after independence, is conceptually the same type of challenge – with greater complexity. For example, the US Department of Defense is interested in demographic distributions around oil fields (by ethnic group) and before and after independence. Alternatively, UNEP is interested in $CO_2$ emissions per capita given that these are oil-producing regions. On the other hand, foreign investors will be interested in insurance rates before and after independence.

The information shown as footnotes in Table 2 (e.g., "Population in millions") illustrates **context knowledge**. Sometimes this context knowledge is explicitly provided with the source data (but still must be accessed and processed), but many times it must be found in other sources, and on occasion someone must be asked to explain the meaning of the data. The good news is that such context knowledge almost always exists, but it is often widely **distributed** within and across organizations. Thus, a central focus of this part of the effort is to support **the acquisition, organization, and effective intelligent usage of distributed context knowledge to support information harmonization and collaborative domains**.

### 3.3 Research Platform

The MIT COntext INterchange (COIN) Project has developed a platform including a theory, architecture, and basic prototype for such intelligent harmonized information processing. COIN is based on database theory and mediators [Wied92, Wied99] the evolution of the web, the importance of data semantics, and the strong relationship among global research and standard setting bodies (e.g., W3C, Semantic Web efforts). Context Interchange is a mediation approach for semantic integration of disparate (heterogeneous and distributed) information sources. It has been described in [BGL*00 and GBM*99]. The Context Interchange approach includes not only the mediation infrastructure and services, but also wrapping technology and middleware services for accessing the source information and facilitating the integration of the mediated results into end-users applications (see Figure 1).

The wrappers are physical and logical gateways providing uniform access to the disparate sources over the network [FMS00a, FMS00b]. The set of Context Mediation Services, comprises a Context Mediator, a Query Optimizer and a Query Executioner. The Context Mediator is in charge of the identification and resolution of potential semantic conflicts induced by a query. This automatic detection and reconciliation of conflicts present in different information sources is made possible by ontological knowledge of the underlying application domain, as well as informational content and implicit assumptions associated with the receivers and sources.

The result of the mediation is a mediated query. To retrieve the data from the disparate information sources, the mediated query is then transformed into a query execution plan, which is optimized, taking into account the topology of the network of sources and their capabilities. The plan is then executed to retrieve the data from the various sources, results are composed and sent to the receiver.

In a heterogeneous and distributed environment, the mediator transforms a query written in terms known to the user or application program (i.e., according to the user's or programmer's assumptions and knowledge) into one or more queries in the terms of the component sources. The individual subqueries may still involve several sources. Subsequent planning, optimization and execution phases are needed [AKS96, Fynn97]. The planning and execution phases must consider the limitations of the sources and the topology and costs of the network (especially when dealing with non-database sources, such as web pages or web services). The execution phase is in charge of the scheduling of the query execution plan and the realization of the complementary operations that could not be handled by the sources individually (e.g. a join across sources).

Where a large number of independent information sources are accessed (as is now possible with the global information infrastructure), flexibility, scalability, and non-intrusiveness will be of primary

importance. Traditional tight-coupling approaches to semantic interoperability rely on the *a priori* creation of federated views on the heterogeneous information sources, which do not scale-up efficiently given the complexity involved in constructing and maintaining a shared schema for a large number of, possibly independently managed and evolving, sources. Loose-coupling approaches rely on the user's intimate knowledge of the semantic conflicts between the sources and the conflict resolution procedures, which becomes a drawback for scalability when this knowledge grows and changes as more sources join the system and when sources are changing. The Context Interchange (COIN) approach is a middle ground between these two approaches. It allows queries to the sources to be mediated, i.e. semantic conflicts to be identified and solved by a context mediator through comparison of contexts associated with the sources and receivers concerned by the queries. It only requires the minimum adoption of a common Domain Model that defines the domain of discourse of the application.

The knowledge needed for harmonization is formally modeled in a COIN framework [Goh96], The COIN framework is a mathematical structure offering a sound foundation for the realization of the Context Interchange strategy. The COIN framework comprises a data model and a language, called COINL, of the Frame-Logic (F-Logic) family [KLW95, DT95]. The framework is used to define the different elements needed to implement the strategy in a given application:

- The Domain Model is a collection of rich types (semantic types) defining the domain of discourse for the integration strategy;
- Elevation Axioms for each source identify the semantic objects (instances of semantic types) corresponding to source data elements and define integrity constraints specifying general properties of the sources;
- Context Definitions define the different interpretations of the semantic objects in the different sources or from a receiver's point of view.

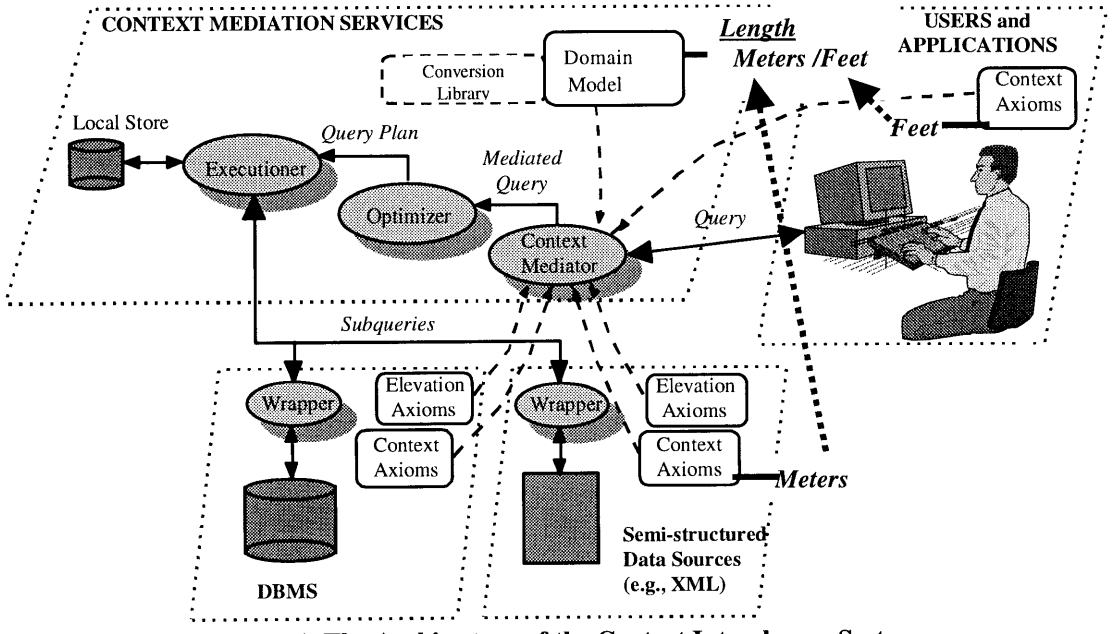


**Figure 1. The Architecture of the Context Interchange System**

The comparison and conversion procedure itself is inspired by the Abductive Logic Programming framework [KKT93] and can be qualified as an abduction procedure, to take advantage of its formal logical framework. One of the main advantages of the abductive logic programming framework is the simplicity in which it can be used to formally combine and to implement features of query processing, semantic query optimization and constraint programming.

### 3.4. Research Tasks and Expected Contributions

Although the existing COIN system and its underlying research provides a powerful "head start" and platform for harmonized information processing, it is still inadequate to address all the needs illustrated in Sections 1 and 2. Performing the important research to address these additional requirements and to produce our System for Harmonized Information Processing is the primary focus of this part of the effort.

**1. Extended Domain of Knowledge – Functionally Dependent Data and Temporal Context.** In addition to the types of domain and context knowledge currently handled by the COIN framework, we need to perform research to add capabilities for both the representation and reasoning to provide support for functionally dependant data and temporal context. Functionally dependant data refers to the knowledge such as "average GDP per person (AGDP)" means "total GDP" divided by "population." In some data sources, AGDP explicitly exists (possibly with differing names and in differing units), but in other cases it may not explicitly exist but could be calculated by using "total GDP" and "population" from one or more sources – if that knowledge existed and was used effectively. Temporal context refers to the fact that context not only varies across sources but also across time. Thus, the implied currency context for France's GDP prior to 2002 might be French Francs but after 2002 it is in Euros. If one were performing a longitudinal study over multiple years from multiple sources, it is important that this variation in context over time be understood and processed appropriately.

**2. Collaborative Domain Spaces.** The existing COIN framework provides representation and reasoning capabilities for a single domain. Although there are a number of ontology library systems that allow for management of multiple ontologies [DSW*99, DFen01 Fensel01, HelfH00], they have limitations in scalability and dynamically incorporating new ontological knowledge. Especially, they lack the capability of representing rich context knowledge needed for reconciling differences among sources. The primary focus of this overall research effort, and driven by the international relations setting, is the ability to operate in a multi-disciplinary environment across multiple collaborative domain spaces. The representational capabilities to effectively relate concepts across domains, and efficiently maintain the effectiveness of these collaborative domain spaces is critically important – especially in an environment where we believe the underlying domains themselves will continually undergo evolution.

**3. Advanced Mediation Reasoning and Services.** The COIN abductive framework can also be extrapolated to problem areas such as integrity management, view updates and intentional updates for databases. Because of the clear separation between the declarative definition of the logic of mediation into the COINL program from the generic abductive procedure for query mediation, we are able to adapt our mediation procedure to new situations such as mediated consistency management across disparate sources, mediated update management of one or more database using heterogeneous external auxiliary information or mediated monitoring of changes. Although there are fundamental theoretical limits in many areas, such as view update, we can extend the range of current mediation services to handle a broader range of client needs. The mediated update problem illustrates the potential advantage of the formal logical approach in COIN over traditional view mechanisms for mediation. The COIN approach, however, holds the knowledge of the semantics of data in each context and across contexts in declarative logical statements separate from the mediation procedure. An update asserts that certain data objects must be made to have certain values in the updater's context. By combining the update assertions with the COIN logical formulation of context semantics, we can determine whether is unambiguous and feasible, and if so, what source data updates must be made to achieve the intended results. If ambiguous or otherwise infeasible, the logical representation may be able to indicate what additional constraints would clarify the updater's intention sufficiently for the update to proceed. We will build upon the formal system underlying our current framework, F-Logic and abductive reasoning, and extend the expressiveness and the reasoning capabilities leveraging ideas developed in different yet similar frameworks such as Description Logic and classification.

**4. Automatic Source Selection.** A natural extension is to leverage context knowledge to achieve context-based automatic source selection. One particular kind of context knowledge useful to enable automatic source selection is the content scope of data sources [TM98]. Data sources differ either significantly or subtly in their coverage scopes. In a highly diverse environment with hundreds and thousands of data sources, differences of content scopes can be valuably used to facilitate effective and efficient data source selection.

Integrity constraints in COINL and the consistency checking component of the abductive procedure provide the basic ingredients to characterize the scope of information available from each source, to efficiently rule out irrelevant data sources and thereby speed up the selection process. For example, a query requesting information about *companies with assets lower than $2 million* can avoid accessing a particular source based on knowledge of integrity constraints stating that *the source only reports information about companies listed in the New York Stock Exchange* (NYSE), and that *companies must have assets larger than $10 million to be listed in the NYSE.* In general, integrity constraints express necessary conditions imposed on data. However, more generally, a notion of completeness degree of the domain of the source with respect to the constraint captures a richer semantic information and allows more powerful source selection. For instance, a source could contain exactly or at least all the data verifying the constraint (e.g., all the companies listed in the NYSE are reported in the source).

**5. Source Quality and Attribution Knowledge Processing.** Not only do the sources vary in semantic meaning, they also vary in quality. We must be able to represent and reason about the quality attributes of the sources. Furthermore, for quality and other reasons, it is important to know the attribution of the sources [LCN*99, LMB98]. For example, it can be important to know that although three different sources agree on a controversial piece of the information, all three sources acquired that information from the same, maybe questionable, origin source. Thus, attribution metadata must be represented and processed. Although some basic research in these issues of quality and attribution has occurred, these areas must be further advanced and ultimately incorporated into the system.

**6. Domain Knowledge Processing – Improving Computer Performance.** While domain and context knowledge processing has been shown to have considerable conceptual value [MBM*98, LMS96b], its application in real situations requires both efficiency and scalability across large numbers of sources, quantities and kinds of data, and demand for services. The scalability and optimization of this mediation processing for large numbers of sources across multiple collaborative domains and contexts will be important.

**7. Domain Knowledge Acquisition – Improving Human Performance.** Domain and context knowledge acquisition are also very important. One essential property to be emphasized is the independence of the domains and sources. Our approach is non intrusive and respects their independence. Our strategy employs a top down approach starting from the receiver's requirements. To effectively use the expressive power of the constructs and mechanisms in COINL, users must be given assistance for the construction of domain and context knowledge. It is therefore essential to develop an appropriate methodology, and the tools supporting this methodology.

**8. Operational System for Harmonized Information Processing** A critical goal of this project is to significantly advance existing research and develop the new research areas required to provide a comprehensive System for Harmonized Information Processing that will be used to support the International Relations inquiries and challenges listed in Section 2. It is essential that this system be developed with maximum flexibility, and extensibility that will permit new and existing applications to seamlessly extract data from an array of changing heterogeneous sources.

## Section 4. Laboratory for Information Globalization and Harmonization Technologies

The **Laboratory for Information Globalization and Harmonization Technologies (LIGHT)** will be established to address the strategy, application, development and deployment of intelligent

information technologies that support the study of complex issues of the 21st century. Its purpose is to examine 'frontier' issues, such as transformations in patterns of conflict and cooperation, changes in modes of international business, emergent dimensions of globalization, and negotiations for new global accords, among others. In addition to the research activities, the lab will host the technical infrastructure of the project, in particular our System for Harmonized Information Processing, and the publication and dissemination of research tools and findings.

In practice, the research activities in this multidisciplinary Laboratory will bring together faculty and students with interdisciplinary interests from a number of departments of MIT, including Computer Science, Political Science, Management Science, and the Technology, Management and Policy program, as well as key research centers relevant to this work, notably the Center for Technology, Innovation, and Policy Development (CTIPD) and the Center for International Studies (CIS)

The Laboratory will be the central entity for producing products in four areas: (I) Software Platforms, (II) Knowledge Repositories, (III) Application Demonstrations, and (IV) Education and Research. The software platforms will include but not be limited to: Collaborative Domains Space (CDS) Systems including one or more Ontology Library Systems, Context and Conversion Management Systems, Context Mediation Engine, Execution and Planning Module, and Application and Source Support Tools. The Knowledge Repositories will include both the structure and the content to define a significant portion of the knowledge needed for applications from International Relations. The IR domain specific knowledge will be represented in ontologies, context and conversion libraries, source schemas and capabilities. The Application Demonstrations will be developed at MIT, with cooperation from collaborators. There will be significant effort focused on technology transfer and open source Web presence. In Education and Research, the Laboratory will have three sets of outreach activities to the scholarly and the policy communities: (a) an ongoing Workshop on Innovations in Information Management, designed largely for experimental work across disciplines and domains, (b) a periodic Symposium on Globalization and Advances in Information Technology, targeted as an interface to the national and international policy-making communities, and (c) a web site that will include access to our System for Harmonized Information Processing, ongoing research activities, an electronic discussion forum, and useful links that are relevant to our research. The Laboratory will also issue its own working papers and, as appropriate, organize its Book series, potentially with the MIT Press, and coordinate the Project's educational activities and materials.

## Section 5. Educational Impacts

This multidisciplinary project addresses large-scale issues that will bring together graduate students with interdisciplinary interests from a number of departments of MIT. Integration of the research project into the education of these disciplines will train students to have multidisciplinary skills and prepare them for tackling even more complex problems in their research career.

We expect that the approach and technology platform developed in the project will be integrated in classrooms and be used for developing new curriculum, which will fundamentally change how knowledge is conveyed and significantly enhance the effectiveness of education. For example, political science students will be able to focus their effort on analyzing issues of crisis management without spending much time in looking for relevant information; computer science students will be able to practice their skills by creating applications of other domains on top of the provided platform. We also plan to design new educational venues in "IR and IT" (drawing on the joint capabilities and developments evolving from our System for Harmonized Information Processing,) to enable multidisciplinary education and research. This may take a number of forms, e.g., joint-supervision of Ph.D. students; hosting post-doctoral researchers; knowledge dissemination and experience sharing through seminar series and regular workshops, etc. We anticipate that the impact to education will be profound and continuous as our

international collaborators begin to adapt the project's curricula to their own contexts and institutional conditions.

## Section 6. Summary of Anticipated Contributions

The outcomes of this major and innovative project will address many of the challenges in each of the NSF's ITR multidisciplinary focus areas. Some examples are:

**1. Software and Hardware Systems.** This project will enable us to create a **robust platform,** the LIGHT System for Harmonization of Information Processing, for **meaningful information interchange** among **very large scale** (in terms of size and geographical locations) and **diversified** (in terms of media, schemas, and domains) systems. **Reliability** of systems built on this platform will be significantly improved by dynamically incorporating semantically equivalent sources into the interconnected system. The general-purpose platform will allow new applications to be built quickly to **facilitate information sharing among groups of people, devices**, and software systems. Since the platform will facilitate semantic level information interchange, any information receiver (people, devices, or software) can get information accurately and in a form and meaning that the receiver prefers.

**2. Augmenting Individuals and Transforming Society.** This project will significantly **augment the effective use of information in our society** and **expand the frontiers of political science and information technology**. We intend to generate empirically-based and systematic insights into how people access and use **large-scale heterogeneous data sources** in a complex domain like IR. These findings will help us to define the requirements for the necessary Collaborative Domain Spaces (CDSs) and meet the goal of **improved information utilization** that also can be applied and extended to other complex fields of study. Through **international collaborators** we will be able to obtain a more robust handle on matters of context, culture, multiple interpretations, multilingualism, imperatives of localization, etc. that will invariably continue to shape the nature of **international relations**. Our approach will advance the frontiers of political science by providing a powerful tool for information-intensive analytical frameworks, which will **change the conduct of political science research**. This contribution also will lead to **more effective use of information in society** enabling **a more informed citizen participation**.

**3. Scientific Frontiers and Information Technology**. A key result of this research will be the capability for effective **domain and context knowledge acquisition and discovery**. The System for Harmonized Information Processing will enable us to gather data from **large-scale heterogeneous sources** and intelligently and effectively **interpret and integrate** it – making possible **the creation of consistent data sets over vast scales of space and time.** This will enable global and strategic decisions to be made timely and informatively.

**4. Education**. Our project will contribute to education in a number of specific ways: it will help to **transform the traditional IT educational setting** by incorporating various disciplines into the development of new IT theories and tools. Similarly, **political science students** will advance their understanding of complex issues in their field through the use of these technologies. In addition, by facilitating the integrated study of complex issues, this research will help to develop and foster new multidisciplinary learning environments. Our project will also contribute to the education of new researchers, including post-doctoral associates, graduate students, and undergraduate students, who will take an active role in the research of this project.

In conclusion, the research team plans to utilize the Internet and the technical infrastructure developed by the new **Laboratory for Information Globalization and Harmonization Technologies (LIGHT)** to share its findings and encourage collaboration with the broader research community. The materials that will be publicly available on the Internet include: literature reviews, survey results, theoretical models, reports, the ***System for Harmonized Information Processing*** technology, other analyses conducted during the life cycle of the project, and a discussion forum. This approach serves two

purposes: potential materials of interest are provided to the intellectual community in a more timely manner than would be possible with traditional academic publications, and the potential for timely and valuable feedback on the research is significantly enhanced. We expect the results will generate profound impacts for the research, education, and various practitioner communities, as well as society, in general.

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## APPENDIX I.
## PROJECT MANAGEMENT PLAN

Recognizing that advances in information technology are essential for achieving the Nation's 21 century aspirations, we propose to integrate and manage all components of the proposed research under a newly created laboratory, named the **Laboratory for Information Globalization and Harmonization Technologies (LIGHT).** The lab will oversee all research activities, host the technical infrastructure, coordinate outreach activities of the project, and disseminate the products of LIGHT research (such as publications, platforms, tools, and educational materials) and host the proposed Symposia and Workshops.

To reinforce intellectual and operational synergy, the laboratory will be jointly run by the co-PIs (Choucri, Madnick, Siegel). One of the PIs (Siegel) will take the key role in the day-to-day management and coordination of the laboratory, assisted by a post-doc. This management team is dedicated to providing results that will directly address information technology problems and applications central to national priorities in IT. Assisting the management team will be a steering committee of collaborators that includes, but is not limited to, the following: AT&T (B. Allenby), Columbia University (R. Jervis), Fletcher School of Law & Diplomacy (L. McKnight), IBM (K. Cavanaugh), MITRE (F. Manola), Sony International Advanced Technology Center (L.G. Scheidt), Stanford University (M. Feldman), US Institute for Peace (R. Solomon), and UNESCO (C. von Furstenberg).

The proposed project is composed of three components that will focus on different, but related, areas of interest: (1) identifying barriers to access of information for education, research, decision making, and performance in the complex domain of international relations (**IR**), (2) development of new information technologies (**IT**) to address these needs for both IR and similarly complex domains, where there are multiple actors and domains of salience, and (3) advancing developments in the use of the technologies to facilitate interdisciplinary research and contribute to new education approaches, tools, and methods.

The IR research component will be managed by one PI (Choucri), and will include the efforts of one full-time doctoral student and multiple research assistants. The IT development will be managed by two co-PIs (Madnick and Siegel), and will include the efforts of one full-time doctoral student and multiple research assistants. The education component of the project will be managed by all three PIs, and will include the efforts of all full-time doctoral students and multiple research assistants. All of the PIs have considerable prior experience with the organization and management of large scale, international, distributed, and diverse research projects.

At the foundation of this proposal is a network of international collaboration buttressed by robust experience and a long track record. These include a wide range of collaborators, each with their own distinctive operational context and expected participation. The list below names some of the initial collaborators (*letters of confirmation from fifteen of the collaborators, **marked with** *, have been received in time to be included in the Supplemental Documents*). The Table highlights four types of contributions: (1) **reviewers** (who contribute valuable input on the research), (2) **data sources** (who provide data for application testing), (3) **users** (potential users of the technology who help with the problem definition and who provide challenging test cases), and (4) **active researchers** in either **IR** and/or **IT** (who will directly participate in and contribute to our research). None of these collaborators will be receiving any of the NSF funds, but they will significantly leverage the funds that are provided.

| Names and Institutions of Collaborators | Institution Type | Anticipated Roles | Benefits to the Research |
|---|---|---|---|
| * C. von Furstenberg, **UNESCO**<br>B. Plescovic, **World Bank** | International governmental organizations | **Data sources and users,** contributing to understanding of changing policy contexts and impacts on information needs. | Direct inputs on policy deliberations affecting context and framework for implementation of international information systems. |
| * J. Cares, **Alidade Consulting**<br>* P. Brecke, **Georgia Tech, Nunn School of International Affairs**<br>* B. Pollins, **Ohio State University**<br>* M. Feldman , **Stanford University**<br>T. Jahn and E. Becker, **Institute for Sociological Research**<br>A. White and R. Massie, **Global Reporting Initiative** | Scientific research and policy institutions | **Reviewers, users, and active researchers (IR),** who will also participate in workshops and help to develop new applications. | Provide comparative bases for assessing generalizability and collaborate on new applications. |
| * W. R. Baker, **Baker & McKenzie**<br>* L.G. Scheidt, **Sony International Advanced Technology Center**<br>* B. Allenby, **AT&T**<br>* Dan Schutzer, **Citibank**<br>* U. Wennberg, **Global Responsibility, International**<br>K. Cavanaugh, **IBM** | Global firms – Information Technology, Legal Services, Electronics, and Financial Services | **Reviewers and users,** contributing to improved applications to multilingual contexts, including relevance of changing legal contexts to information provision worldwide. Insights into integration issues in large multinational environments with heterogeneous data sources. | Diversity of professional and domain expertise, covering variations in legal contexts, environmental research, and responses to the cultural diversification of the global workplace. |
| * M. Salomone, **Schole Futuro, Italy**<br>* G. Kochendoerfer-Lucius, **German Foundation for International Development**<br>C. Brodhag, **Ecole des Mines a St. Etienne, France**<br>S. Chengyoung, **Ministry of Science & Technology, China** | Governmental scientific agencies | **Data source and active researchers (IR/IT),** contributing to contextual evaluation, cross-cultural interpretation and meanings, local knowledge provision, and comparison across contexts. | Currently working with PI Choucri on global knowledge networking. Direct input into contextual biases, or errors in assignment of meaning to recorded observations. |
| * T. Mezher, **American University, Lebanon**<br>A.Koshla, **Development Alternatives India**<br>M. Tolba, L. Hassenien, **ArabDev, Egypt** | Researchers from institutions in developing countries | **Data source and active researchers (IR),** with a focus on the provision of local and national knowledge. | Currently collaborating with PI Choucri on global knowledge networking. Important to comparative and diverse contextual applications, and the validation of internationalization approach and analysis. |

| Names and Institutions of Collaborators | Institution Type | Anticipated Roles | Benefits to the Research |
|---|---|---|---|
| * F. Manola, **MITRE** | Non-profit corp. operating federally funded R&D centers | **Data sources, reviewers, users, active researchers (IT),** providing input in an application for disaster relief application and into theory and system development. | Currently working with Co-PIs Madnick and Siegel on issues related to Semantic Web. Effective liaison with federal agencies. Substantial knowledge representation and technology experience. |
| * Tan Kian Lee and Stephane Bresson, **National University of Singapore** | National University | **Data sources, reviewers users, active researchers (IT)**, providing lab for development of theory and software platform. | Active database researchers having significant experience with web-based information integration. |

Due to the highly multi-disciplinary nature of this effort, the research will be supported by an outstanding and diverse research team of international collaborators, with multiple demographics, experiences, and qualifications. We believe that this project will lead to important developments in the areas of political science/IR and IT. In particular, their intersection will have a significant impact on the way organizations (e.g., governments, companies, world bodies) understand, react to, and manage the significant global challenges (e.g., war, terrorism, environment) of the 21st century.

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# APPENDIX II.
# FACILITIES, EQUIPMENT, AND OTHER RESOURCES

## COMPUTING EQUIPMENT AND DATA SOURCES

The newly formed **Laboratory for Information Globalization and Harmonization Technologies** will primarily use the existing computing equipment from the Context Interchange Systems (COIN) laboratory (within the Information Technology group of MIT's Sloan School of Management) and the Global System for Sustainable Development (GSSD) project (within MIT's Center for International Studies and Political Science department.) Both facilities are located in the same building, and most on the same floor, so coordination will be easy.

Equipment currently available within the COIN lab includes two Sun Unix servers, a Windows NT server, a Linux server, and 16 current generation Intel workstations running versions of Windows or Linux as appropriate for research needs. Available software includes Microsoft development, systems, and server platforms as well as open source resources for software development, knowledge management, and database management. The latest version of the COIN context mediation prototype, for knowledge representation and reasoning, was developed within this lab and this software infrastructure will constitute a starting point for the proposed effort.

In addition, we will draw on the two Pentium workstations and 3 Windows NT servers, and data sources of the GSSD. GSSD is the knowledge management system for the Alliance for Global Sustainability (which includes MIT, U of Tokyo, Chalmers University-Sweden, and ETH - the Swiss Technical University System). GSSD mirror sites are maintained in France (École Nationale Supérieure des Mines de Saint Etienne), China (Ministry of Science and Technology) and Japan (University of Tokyo).

**OTHER RESOURCES**

As part of its dual focus on education and research, there are more than 3,000 ongoing projects on campus at MIT. These projects utilize shared centralized facilities, such as contemporary computational aids and library facilities, as well as specialized facilities of individual departments, research centers, and labs. Each project is affiliated with a nodal department, but can access resources in other parts of MIT. This project will draw particularly on MIT's extensive network infrastructure and MIT's OpenCourseWare initiative, which reflects MIT's institutional commitment to disseminate knowledge across the globe.

As part of this research effort we plan to work with collaborators as reviewers, data sources (who provide data for application testing), users (potential users of the technology who help with the problem definition and who provide challenging test cases), and active researchers in either IR and/or IT (See Management Plan for more details). As a result of the active participation of these collaborators (i.e., international and governmental organizations, scientific research and policy institutions, researchers from institutions in developed and developing countries, global commercial firms, non-profit organizations and universities) we expect to have access to and involve a number of resources from these organizations, including databases, applications, algorithm and theory development, software, and facilities for meetings and demonstrations.

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