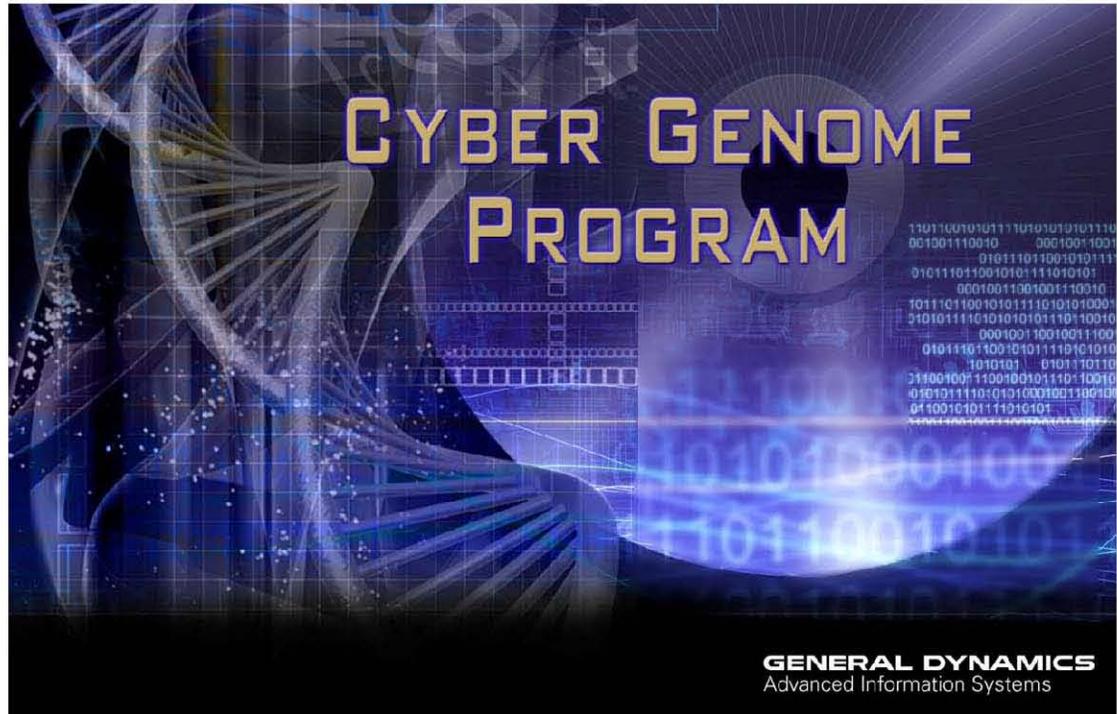


Proposal for R&D Support of DARPA Cyber Genome Program



For Defense Advanced Research Projects Agency
Security & Intelligence Directorate
3701 North Fairfax Drive
Arlington, VA 22203-1714

GENERAL DYNAMICS
Advanced Information Systems

Date: March 29, 2010

Proposal for R&D Support of DARPA Cyber Genome Program

Volume 1 Technical and Management Proposal

Submitted to
Defense Advanced Research Projects Agency
Security & Intelligence Directorate
3701 North Fairfax Drive
Arlington, VA 22203-1714

Contractor Bid or Proposal Information

Restriction on Disclosure and Use of Data: FAR 52.215-1(e)(1) (Jan. 2004)

This proposal includes data that shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed—in whole or in part—for any purpose other than to evaluate this proposal. If, however, a contract is awarded to this offeror as a result of—or in connection with—the submission of this data, or the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the resulting contract. This restriction does not limit or the Government's right to use information contained in this data if it is obtained from another source without restriction. The data subject to this restriction are contained in sheets that carry the legend of FAR 52.215.1 9(e)(2) (JAN 2004).

General Dynamics Advanced Information Systems, Inc. (GDAIS) - PROPRIETARY

This document contains confidential, trade secret, commercial or financial information owned by General Dynamics Advanced Information Systems, Inc., and is voluntarily submitted for evaluation purposes only. It is exempt from disclosure under the Freedom of Information Act (5 U.S.C. 552) under Exemptions (b) (3) and (4), and its disclosure is prohibited under the Trade Secrets Act (18 U.S.C. 1905) and FAR 24.202.

This document shall not be copied or reproduced in whole or in part for any purpose whatsoever, other than evaluation. Do not copy or distribute to others without notification pursuant to Executive Order 12600.

LIMITED RIGHTS FAR 52.227-14 (Dec. 2007)

These data are submitted with limited rights under this proposal. These data may be reproduced and used by or the Government with the express limitation that they will not, without written permission of the Contractor, be used for purposes of manufacture nor disclosed outside or the Government; except that or the Government may disclose these data outside or the Government for the following purposes, if any, provided that or the Government makes such disclosure subject to prohibition against further use and disclosure: none.

This notice shall be marked on any reproduction of these data, in whole or in part.

GENERAL DYNAMICS
Advanced Information Systems

2721 Technology Drive
Annapolis Junction, MD 20701

Proposal File Number: A6680

Date: March 29, 2010

Table of Contents

TABLE OF CONTENTS	3
LIST OF FIGURES.....	4
I.A COVER SHEET.....	5
I.B TRANSMITTAL LETTER.....	7
II. SUMMARY OF PROPOSAL	8
II.A INNOVATIVE CLAIMS, TASKS, AND SUBTASKS	10
II.A.1 <i>De-obfuscation of Code</i>	10
II.A.2 <i>Data Flow Mapping Research</i>	11
II.A.3 <i>Unknown Malicious Behavior Detection</i>	12
II.B SUMMARY OF DELIVERABLES	13
II.C SUMMARY OF COST, SCHEDULE, AND MILESTONES	13
II.D SUMMARY OF TECHNICAL RATIONALE, APPROACH, AND PLANS	13
II.E DETAILED MANAGEMENT, STAFFING, ORGANIZATION CHART, AND KEY PERSONNEL	13
II.E.1 <i>Innovative Management Practices</i>	15
II.E.2 <i>Program Management</i>	16
II.E.3 <i>Key Personnel</i>	17
II.F FOUR-SLIDE SUMMARY.....	21
III. DETAILED PROPOSAL INFORMATION.....	23
III.A SOW TASKS AND SUBTASKS.....	23
III.B DESCRIPTION OF RESULTS, PRODUCTS, TRANSFERRABLE TECHNOLOGY, AND TRANSFER PATH	23
III.C DETAILED TECHNICAL RATIONALE	23
III.D DETAILED TECHNICAL APPROACH AND PLAN.....	25
III.D.1 <i>Researching Cyber Genetic Lineage</i>	25
III.D.2 <i>Researching Cyber Genome Mapping</i>	26
III.D.3 <i>Automating Function Extraction</i>	29
III.D.4 <i>Visualization</i>	31
III.E EXISTING RESEARCH COMPARISON.....	31
III.F PREVIOUS ACCOMPLISHMENTS	31
III.F.1 <i>Past Performances</i>	32
III.G PLACE OF PERFORMANCE, FACILITIES, AND LOCATIONS.....	37
III.H DETAILED TEAMING STRUCTURE.....	38
III.I COST SCHEDULES AND MILESTONES.....	39
III.J DATA, INTELLECTUAL PROPERTY, AND PRIVACY.....	41
IV. BIBLIOGRAPHY OF TECHNICAL PAPERS AND RESEARCH NOTES	42
<i>AVI-Secure Decisions</i>	42
<i>HBGary Federal</i>	42
<i>SRI International</i>	44
<i>UC Berkeley</i>	44

List of Figures

FIGURE 1. TASK AREA 1 OVERVIEW.....	9
FIGURE 2. WHAT SIGNATURES WILL LOOK LIKE.....	10
FIGURE 3. GDAIS TEAM.....	14
FIGURE 4. DARPA CYBER GENOME PROGRAM TEAM.....	15
FIGURE 5. RESEARCHING CYBER GENETIC LINEAGE.....	25
FIGURE 6. RESEARCHING CYBER GENOME MAPPING.....	26
FIGURE 7. FINDING CORRELATIONS OF ELEVATED IMPORTANCE.....	28
FIGURE 8. SUMMARY OF PREVIOUS ACCOMPLISHMENTS.....	31
FIGURE 9. SUMMARY OF TEAM MEMBER LOCATIONS.....	37
FIGURE 10. DARPA CYBER GENOME PROGRAM TEAM LOCATIONS.....	38
FIGURE 11. DARPA CYBER GENOME TEAM.....	39
FIGURE 12. PHASE I SCHEDULE.....	40
FIGURE 13. PHASE II SCHEDULE.....	40

I.A Cover Sheet

1	Broad Agency Announcement	DARPA-BAA-10-36 Cyber Genome Proposal	
2	Prime Organization	General Dynamics Advanced Information Systems, Inc.	
3	Proposal Title	DARPA Cyber Genome	
4	Type of Business (Check one)	<input checked="" type="checkbox"/> Large Business <input type="checkbox"/> Small Disadvantaged Business <input type="checkbox"/> Other Small Business <input type="checkbox"/> Government Lab or FFRDC	<input type="checkbox"/> Historically-Black Colleges <input type="checkbox"/> Minority Institution (MI) <input type="checkbox"/> Other Educational <input type="checkbox"/> Other Nonprofit
5	Contractor's Reference Number	A6680	
6	Contractor and Government Entity (CAGE) Code	3CX93	
7	Dun and Bradstreet (DUN) Number	125202536	
8	North American Industrial Classification System (NAICS) Number	541330 – Engineering Services	
9	Taxpayer Identification Number (TIN)	45-0484950	
10	Technical Point of Contact	Mr. Jason Upchurch 8005 S. Chester Street, Centennial, CO 80112 (719) 357-8858 / (888) 821-0059 jason.upchurch@gd-ais.com	
11	Administrative Point of Contact	Mr. Russell Wenthold 1100 NW Loop 410, Ste 600, San Antonio, TX 78213 (210) 442-4207 / (210) 377-0199 russ.wenthold@gd-ais.com	
12	Security Point of Contact	Mr. Charles Brown 3133 General Hudnell Dr, Ste 300, San Antonio, TX 78226 (210) 932-5522 / (210) 932-5585 charles.brown@gd-ais.com	
13	Other Team Members (if applicable)	AVI-Secure Decisions	Dr. Anita D'Amico 6 Bay Ave, Northport, NY 11768 (631) 754-4920, ext 147 / (631) 754-1721 anitad@avi.com Cage Code: 07QY2
		HBGary Federal	Mr. Arron Barr 3604 Fair Oaks Blvd, Bldg B, Ste 250, Sacramento, CA 95864 (916) 459-44727, ext-147 / (916) 481-1460 aaron@hbgary.com Cage Code: 5U1U6
		Pikewerks	Mr. Adam Fraser 105 A Church Street, Madison, AL 35758 (256) 325-0010 / (256) 325-1077 adam.fraser@pikewerks.com Cage Code: 3XYV3

		SRI International	Dr. Phillip Porras 333 Ravenswood Ave, Menlo Park, CA 84025 (650) 859-3232 phillip.porras@sri.com Cage Code: 03652
		UC Berkeley	Dr. Dawn Song 675 Soda Hall Berkeley, CA 94720 CAGE Code:
14	Funds Requested From DARPA	Base Effort: (Phase 1)	<i>Base Effort Cost</i>
			<i>Base Options Cost: (list all)</i>
		Option Effort: (Phase 2)	<i>Option Effort Cost</i>
			<i>Phase II Options Cost: (list all)</i>
		Total Proposed Cost (Including Options)	<i>Total</i>
		Amount of Cost Share	<i>Amount of cost share (if any)</i>
15	Award Instrument Requested	<input checked="" type="checkbox"/> cost-plus-fixed-fee <input type="checkbox"/> cost-contract-no-fee <input type="checkbox"/> cost sharing contract-no fee <input type="checkbox"/> other procurement contract: _____	<input type="checkbox"/> grant <input type="checkbox"/> agreement <input type="checkbox"/> other award instrument: _____
16	Proposers Cognizant Government Administration Office	DCMA Southern Virginia Attn: Ms. Erin Kirkby, DACO 2301 West Meadowview Rd, Ste 103, Greensboro, NC 27407 (336) 855-8791	
17	Proposer's Cognizant Defense Contract Audit Agency (DCAA) Audit Office	DCAA North Carolina Branch Office Attn: Ms. Ann Goodwin, Supervisory Auditor 5440 Millstream Road, McLeansville, NC 27301 (336) 698-8615	
18	Other		
19	Date Proposal Prepared	March 14, 2010	
20	Proposal Expiration Date	July 31, 2010	
21	Place(s) and Period(s) of Performance	AVI-Secure Decisions	6 Bay Ave Northport, NY 11768 July 2010 – June 2014
		HBGary Federal	3604 Fair Oaks Blvd, Bldg B, Ste 250 Sacramento, CA 95864 July 2010 – June 2014
		SRI International	333 Ravenswood Ave Menlo Park, CA 94025 July 2010 – June 2014
		Pikewerks	2214 Mt. Vernon Ave, Ste 300 Alexandria, VA 22301 July 2010 – June 2014
		UC Berkeley	675 Soda Hall Berkeley, CA 94720 July 2010 – June 2014
22	Technical Area (check one)	<input checked="" type="checkbox"/> Technical Area 1 - Cyber Genetics <input type="checkbox"/> Technical Area 2 - Cyber Anthropology and Sociology <input type="checkbox"/> Technical Area 3 - Cyber Physiology <input type="checkbox"/> Technical Area 4 - Other	

I.B Transmittal Letter

II. Summary of Proposal

Current technologies and methods for producing and examining relationships between software products, particularly malware, are lacking at best. The use of hashing or “fuzzy” hashing and matching techniques are conducted at the program level, ignoring any reflection of the actual development process of malware. This approach is only effective at finding closely related variants or matching artifacts found within malware that are only tangent to the development process, such as hard coded IP address, domains, or login information. This matching process is often unaware of internal software structure except in the most rudimentary sense, dealing with entire sections of code at a time, attempting to align matches while dealing with arbitrary block boundaries. The method is akin to an illiterate attempting comparing two books on the same topic. Such a person would have a chance of correlating different editions of the same book, but not much else. The first fundamental flaw in today’s approach is that it ignores our greatest advantage in understanding relationships in malware lineage, we can deduce program structure into blocks (functions, objects, and loops) that reflect the development process and gives software its lineage through code reuse.

Current correlation techniques cannot achieve lineage

- Do not reflect code reuse
- Use arbitrary boundaries
- Not context aware
- Taxa-based on behavior, not implementation

Software development has been driven to code reuse through economics. It is simply cheaper and more effective to reuse portions of code that have already been developed for a particular task. Entire computer programming languages have been developed to make code reuse more effective. The development of malware also reflects code reuse, not so much through intentional design for the development processes, but because malware is largely developed singularly or in small, tight knit, groups. Code reuse does occur between groups, but this is largely due to theft of code. Code reuse, in either case, is the basis for software lineage; therefore, any attempt to map and correlate cyber genomes should focus on attempting to correlate software reuse.

Reliable correlation of software based on code reuse will establish lineage; however, lineage itself is only of partial value. Code used in legitimate software is not confined to reuse in only other legitimate software. Malware authors reuse code from all sources, legitimate or not. Therefore, lineage without context in malware research is not strictly confined to malware, nor do genetic relationships of an unknown software sample to that of a known malicious sample suggest malignancy. Therefore, the second fundamental flaw in malicious software lineage and correlation approaches to date is that they ignore context.

Malware classification schemes today are based on behavior and largely ignore how those behaviors are achieved unless the information is valuable in developing detection signatures. Behavior itself, while important, is nearly worthless information in any attempt to develop a workable cyber lineage system. Behavior classification is not a viable taxonomy system at all and if such a system were to be applied to biology, an anteater and many birds would belong to the same “family” simply because their behavior, namely eating ants, is the same.

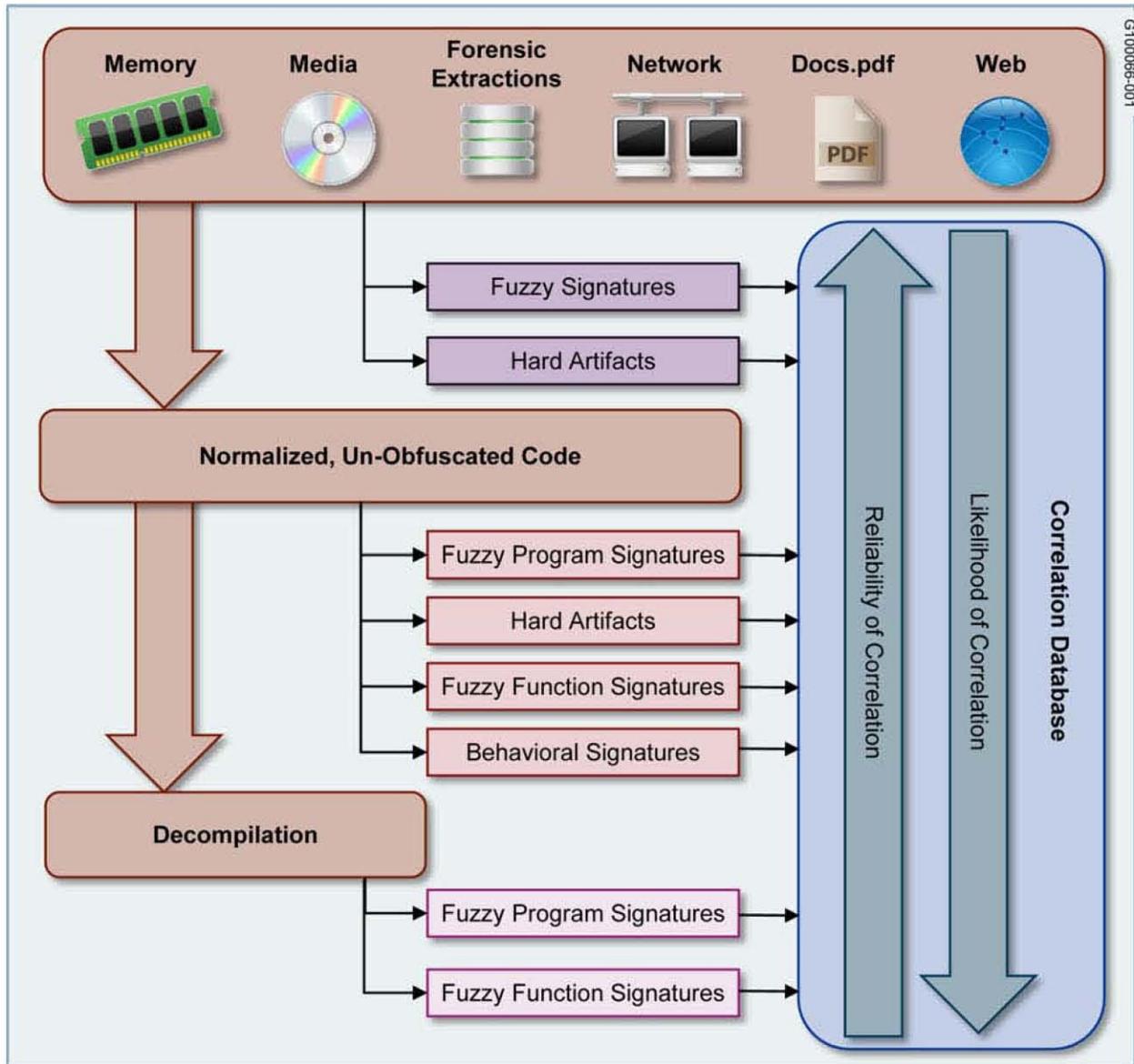


Figure 1. Task Area 1 Overview

What is of use in lineage is how behaviors are achieved. A workable lineage system would classify two key loggers as related, not because they both log keystrokes, but because they achieve this behavior in the same way. That is, they share a function or group of functions within their code base achieves this functionality. With this type of information a viable taxonomy system could be developed, similar the Linnean taxonomy system of the animal kingdom, that reflects actual relationships and lineage.

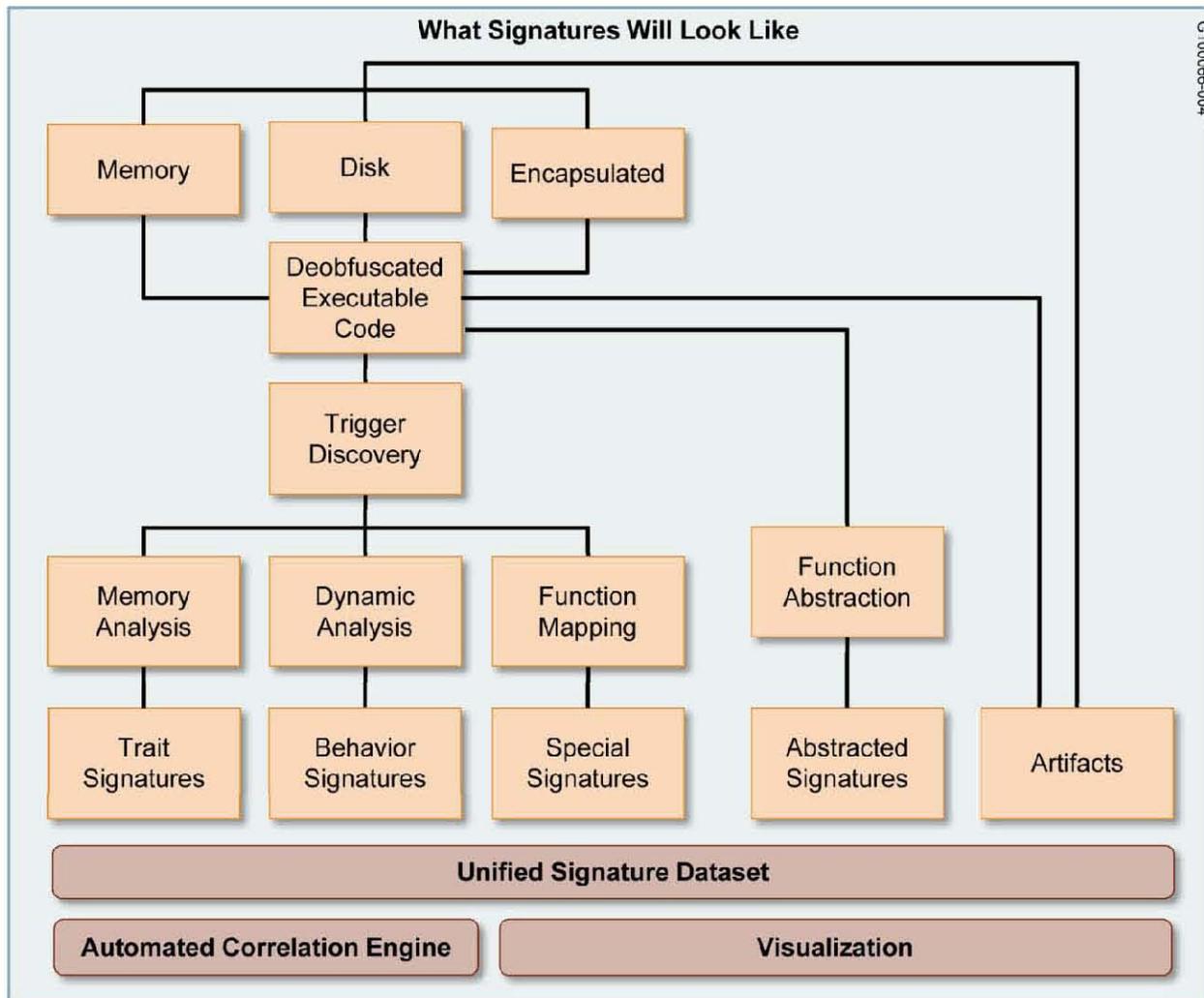


Figure 2. What Signatures Will Look Like

II.A Innovative Claims, Tasks, and Subtasks

II.A.1 De-obfuscation of Code

In an attempt to frustrate analysis, the authors of malware often process their programs using a technique called binary code packing. Code packing transforms a program into a packed program by compressing and/or encrypting the original code and data into packed data and associating it with a restoration routine. The restoration routine is a piece of code for recovering the original code and data as well as setting an execution context to the original state when the packed program is executed. By concealing the program code responsible for malicious behavior, packing is an obstacle to any analysis technique that depends on examining code, from signature-based anti-virus detection to sophisticated static analysis.

There are tools like the CERT CC Pandora, the Navy Research Lab Packer Cracker, PolyUnpack, RL!dePacker, QuickUnpack and others that try to remove the obfuscation layer from the malware, but they are far from being an automated solution that can de-obfuscate large amount of differently obfuscated malware binaries. Many times, they can't provide a de-

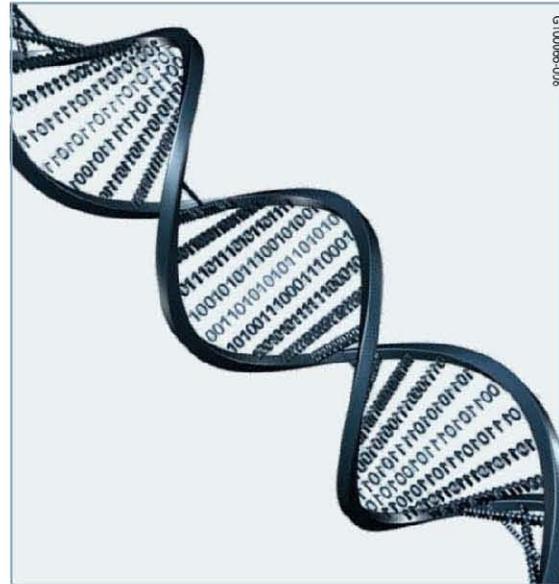
obfuscated or fully functional version of the malware binary, and they observe very poor runtime performance.

A major challenge with some of the obfuscated malware is with the ones that implement thousands of polymorphic layers, revealing only a portion of the code during any given execution stage. Once the code section is executed, the packer then re-encrypts this segment before proceeding to the next code segments.

Another challenge is that malware authors will adapt their packing methods to detect the unpacking tool or to circumvent the unpacking tool process by tracking methods or API hooks.

By adapting and evaluating existing techniques from computational biology (CB), we will provide automated ways of systematically undoing the work of obfuscators to restore the binary to an equivalent but un-obfuscated form. This will be done by using binary rewriting techniques. Decompilation research and techniques will be explored to recover a high-level C and C++ source code of the binary code in order to validate the recovery of a valid and fully functional executable. By assessing the quality of the source code, we will assess the quality of the de-obfuscation steps and improve it accordingly. Computational biology (CB) techniques will be used to tackle the problem of comparing obfuscated malware code segments. Error Correcting Codes (ECC) research and techniques will be used to determine the degree of original similarity.

Research will be performed to use data mining techniques over a set of artifacts, in order to determine the probability of different obfuscation types. Research will also be performed to generate Malware Markov Models to transform any artifact into any other and calculate a probability of that transformation. This probability represents distance between the two artifacts. Using this additional techniques a robust prototype will be built that can handle packers that naively employ multiple layers such as MoleBox and some incremental packers such as Armadillo. In order to counter polymorphic/metamorphic multiple encryption layers, we will research techniques to dump a continuous series of execution/binary images, evaluating each dumped image to choose the image with the optimal analyzability metrics.



II.A.2 Data Flow Mapping Research

To provide a detailed analysis, one of the challenges is to accurately model the effects of each assembly language instruction. To do this, it is necessary to accurately model the effects of each instruction. But that can be difficult; for instance, the standard x86 architecture has hundreds of instructions, which often have implicit side effects, complex addressing modes, and even operand-dependent semantics.

We will perform revolutionary research and develop techniques to translate instructions into an intermediate language with uniform semantics and only about a dozen kinds of statement. This will significantly simplify further analysis. This approach is not to be confused with

decompilation. The goal is not to recover a higher-level language representation of the code, but to analyze assembly as a first class language. On top of this language, we will perform research to provide a rich library of code for manipulating and performing automated analysis on represented binary code. With this technique/capability, we will be able to build control flow graphs and program dependence graphs, perform data-flow analyses such as global value numbering and dead code elimination, and slice or chop to select only the part of code relevant for a query. Under this research, we will develop techniques to interface with bit-precise decision procedures to perform automated reasoning about code, such as to find inputs that satisfy a given set of conditions.

II.A.3 Unknown Malicious Behavior Detection

Dynamic taint analysis is a powerful approach for detecting and analyzing attacks against the integrity of a security-critical application, such as if a network attacker attempts to take control of a service by supplying inputs that give the attacker control over the application's behavior. The basic principle of taint analysis is to mark the untrusted inputs to a program (as "tainted"), and then propagate the tainting status during execution to other values that are computed from these tainted inputs. If a tainted value reaches a sensitive operation, this suggests that an attacker could have control over that operation. For instance, if tainting propagates from an untrusted network request to a value used as a return address in a network server, this could indicate an attack in which the application is about to jump to code of the attacker's choosing.

Taint analysis is a widely used technique, but in its simplest form it also has some widely-encountered limitations. These can be categorized as under-tainting, which occurs when a value that should be tainted is not, and over-tainting, which occurs when values that should not be tainted are not tainted. Under-tainting most often occurs because dynamic taint analysis fails to fully track what are called "implicit flows:" for instance, the fact that the a value loaded from memory depends on the address from which the load occurred, or effects on data that are mediated by control flow. Special case rules, such as for the treatment of lookup tables, can reduce such under-tainting, but a more general approach is needed.

Over-tainting or "taint explosion" can be triggered by a small initial error, causing a single value to be tainted unnecessarily, that leads to significant over-tainting when that value is itself used in many places. Intuitively, this occurs because standard tainting has no way of diluting taint that propagates too widely. Over-tainting can particularly be an issue in a taint analysis engine that emulates an entire system: tainting is valuable for tracking inter-application information flows, but over-tainting that propagates to the kernel can invalidate results for the entire system.

To overcome the challenges of under-tainting, two different research approaches will be studied. One of the research approaches will be performed to detect the occurrence of under-tainting by analyzing how much of the variability of tainted values is propagated to memory addresses and control-flow decisions. If the tainted input is completely determined by such implicit flows, under-tainting is likely to have occurred. The second research area will address instances of under-tainting by an automatic, conservative estimate of the side-effects of code regions whose execution might be under the influence of tainted control flow.

To overcome the challenges of over-tainting, research will be performed to detect such over-tainting by generalizing taint to a continuous attribute, so that a value can have an intermediate level of taint if its propagation has been attenuated. Another research area will be to introduce

special rules for taint propagation across the system call interface, to prevent spurious tainting while preserving correctly tainted values.

II.B Summary of Deliverables

Deliverables associated with the proposed research and the plans and capability to accomplish technology transition and commercialization. Include in this section all proprietary claims to the results, prototypes, intellectual property, or systems supporting and/or necessary for the use of the research, results, and/or prototype. If there are not proprietary claims, this should be stated.

II.C Summary of Cost, Schedule, and Milestones

Cost, schedule and measurable milestones for the proposed research, including estimates of cost for each task in each year of the effort delineated by the prime and major subcontractors, total cost and company cost share, if applicable. Note: Measurable milestones should capture key development points in tasks and should be clearly articulated and defined in time relative to start of effort. These milestones should enable and support a decision for the next part of the effort. Additional interim non-critical management milestones are also highly encouraged at a regular interval.

II.D Summary of Technical Rationale, Approach, and Plans

Technical rationale, technical approach, and constructive plan for accomplishment of technical goals in support of innovative claims and deliverable production. (In the proposal, this section should be supplemented by a more detailed plan in Section III.)

II.E Detailed Management, Staffing, Organization Chart, and Key Personnel

GDAIS offers an innovative approach to teaming and delivering revolutionary cyber research that minimizes the need for GDAIS management and oversight.

Our team uses a streamlined management approach that maximizes the existing strengths of all teammates to provide revolutionary research results and minimize program overhead of a comprehensive team. Our management approach is derived from our vision and strategy. Our vision provides revolutionary technologies for cyber forensics and defense. Our strategy teams proven leaders in key cyber research areas, technology development and forensics who are personally committed to network security. Our team provides a breadth of relevant operational, developmental and research credentials and depth of industry and academia experience in science, technology development, systems integration and capability transition to operational customers. GDAIS researched, down selected and created this team to become a trusted and valued mission partner

Revolutionary Focus, Multiple Talents – Efficient Accomplishment of Cyber Genome Objectives

- Key personnel are experienced DC3 leaders in technology, forensics and leadership.
- Our team of academic and industry leading cyber security experts provide the state of the art technology and research base to apply to provide a revolutionary program.
- We employ innovative business practices to research, integrate and manage the combined efforts to maximize technologies applications to cyber security.
- Out proactive team of independent malware researcher in new technology with proven processes for integration and mission benefit.
- Our integrated master schedule provides prudent milestones and deliverables to assess progress toward successful program goals.

to provide a comprehensive solution to cyber security technology needs and a partner in transitioning technology and prototypes to operators.



Figure 3. GDAIS Team

Figure 1 below identifies our team, organizational structure, key personnel and key capabilities of team members to provide a comprehensive cyber research program. GDAIS leads the team with our principal investigator (PI) and program manager (PM). Our PI is responsible for the technical leadership and direction of the program and teammates, integration of research results from all team members, and the end result, a functioning cyber lineage prototype. Our PI receives support from a DARPA experienced PM and staff to monitor, manage and report program execution and status, contracting and subcontracting, and finance. More details of these responsibilities follow later in this section. Our teammates, SRI, UC Berkeley, Pikewerks, HB Gary and AVI-Secure Decisions are all subcontracted to GDAIS with unique statements of work identifying their tasks, deliverables, schedules and relationships with GDAIS and other teammates for successful execution of the program. Each teammate is responsible for execution of their portion of the program, delivery of research and technology prototypes, and reporting status back to GDAIS monthly who then reports to the DARPA program manager. All teammates are integrated in the quarterly review and reporting process with DARPA to further assure a comprehensive assessment of program status.

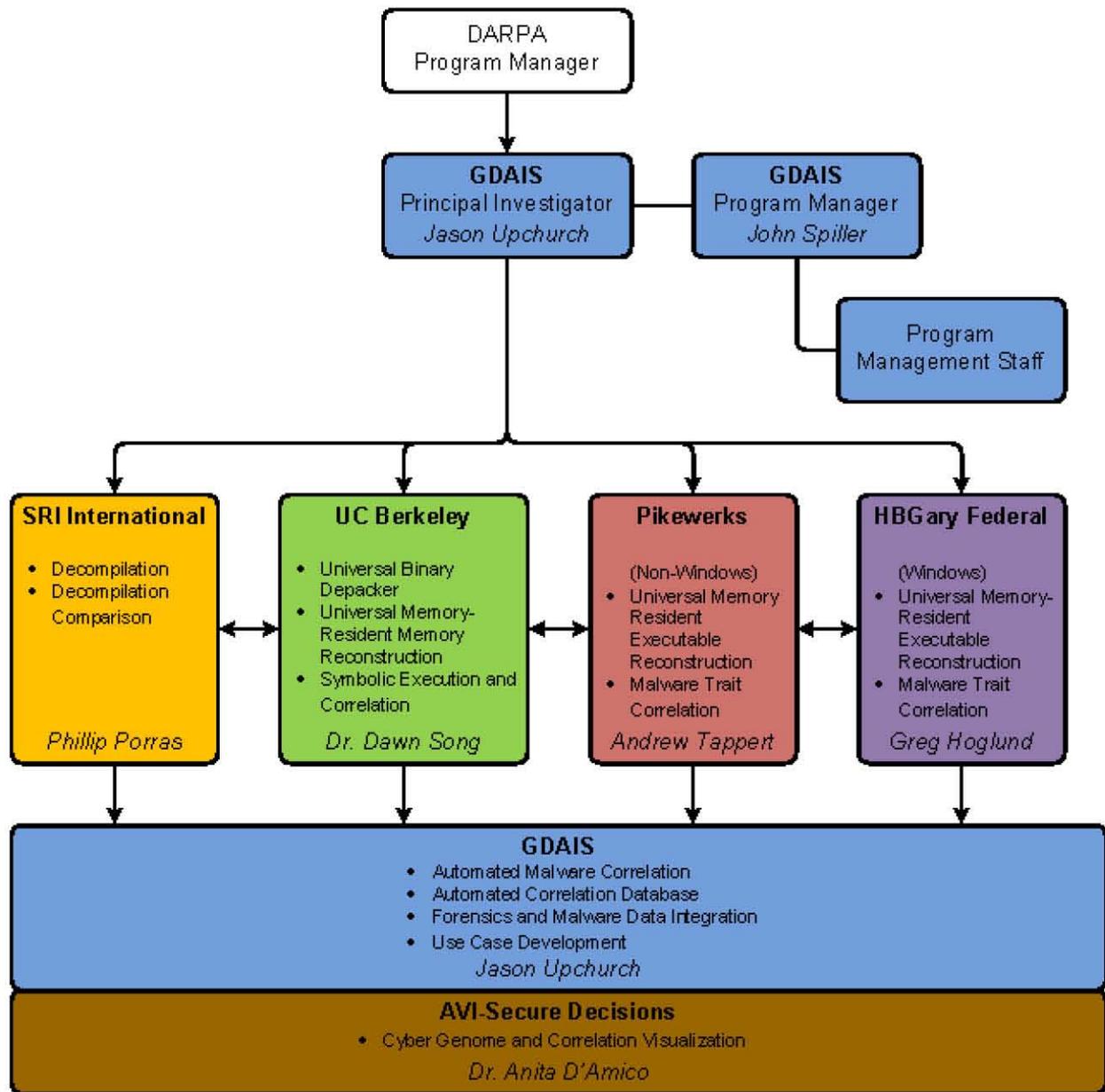


Figure 4. DARPA Cyber Genome Program Team

Our proposal identifies the driving research and technologies needed to achieve program goals, delivery and integration milestones, and provides specific deliverables by phase to assess progress towards goals. The best skill sets for the program reside with the Defense Cyber Crime Center, academia, research institutions and industry. Our team of known professionals are malware, forensics and computer network defense (CND) subject matter experts (SMEs).

II.E.1 Innovative Management Practices

Our innovative business practice provides a proven team to the Cyber Genome Program. We can manage delivery on all schedules for less overall cost to the Government because an already

integrated team is in place for all teammates. Communication paths have been established and practiced with daily telecoms during proposal development and working relationships started. Since there is no spin-up time for our team and because there are fewer communication paths between team members, we can make the overall program more productive.

We recognize that because of the nature of technology research, new team members may be required during the execution of the program to meet unforeseen needs. GDAIS can meet time-sensitive surge, replacement, and new staffing requirements. Our process ensures that the right staff is hired, providing the continuous availability of highly qualified personnel to meet all assigned tasking. GDAIS program management staff is experienced at identifying new requirements, codifying needs into statements of work and effectively responding to program shifts by identifying new teammates and bringing them on to fulfill program requirements in days. Our teams experience in the forensics and computer security mission areas provide us with the connections into additional academic, research and industry sources to identify the skill necessary to address unforeseen challenges.

II.E.2 Program Management

Together, the GDAIS PM and PI continuously review the staffing and technology needs, execution status and progress of our research to meet program goals. Our management processes include lessons learned to improve execution efficiency, assure technical progress and prototype demonstrations that meet the research goals of the program.

We also have a full-service Program Management Office (PMO). The PMO is made up of the PM, a Contracts Administrator, and a Financial Analyst. In short, we can bring to bear the full power, experience, and processes of GDAIS quickly and effectively, but only as necessary. Our PM is a certified Project Management Professional. Thus, he understands the mission and how to lead the technical team without hovering over them. He has set up a lean PMO to support this task. The result is an innovative management structure that has already proven to be highly efficient and effective.

Security (if required), Finance, Contracts, and Purchasing are required back-office functions to professionally execute this task within the funding provided, are staffed with cleared personnel, and efficiently find effective solutions to meet the Statement of Work (SOW) and exceed expectations. All support functions are handled by employees with years/decades of experience in, trained in, and dedicated to that specific profession. To provide the greatest value to the customer, however, the PM employs these back office resources only as needed and only with the full knowledge and consent of the customer. This produces a lean back office overhead and maximizes the funding toward meeting the technical requirements of the SOW. Professional staff, employed only when and where needed spread across multiple contracts, are the key to efficient and effective business practices. Flexibility and mission-focus are the keys to our fantastic customer relationships.

We do not need on-site management of our teammates because all are experienced professionals. All of GDAIS employees are authorized to represent GDAIS so we do not have to play a “mother may I” game when working with teammates. Our PI is specifically charged with ensuring each member of our team meets or exceeding all research expectations and that they all understand that integrating with other team members is their personal responsibility.

Our technical work is primarily located at Annapolis Junction, Maryland and teammates existing

locations.

II.E.3 Key Personnel

II.E.3.1 Jason Upchurch, GDAIS Key Person

Jason Upchurch, Senior Technical Lead for Intrusions Forensics at GDAIS	
Proposed Role:	Principal Investigator
Proposed Level of Support:	75%
Education:	B.S. Computer Science, Regis University, 2007
Location:	Centennial, Colorado
<p>Mr. Upchurch has extensive experience as a technical manager and subject matter expert in malware analysis and intrusion forensics. He is currently a senior technical lead for GDAIS Cyber Systems. He is responsible for leading incident response and forensics relating to computer intrusions and reports to the Director of Cyber Systems. In addition, he provides mentoring/coaching to other cyber systems personnel, develops automation techniques for digital forensics, and provides training both internally and externally on Malware Analysis and Large Dataset Forensics. He has presented at conferences at the national and international level.</p> <p>Mr. Upchurch was the technical lead and contract manager for both the Defense Computer Forensics Laboratory (DCFL) Intrusion Section, to include the malware analysis unit, and the contract personnel in the National Cyber Investigative Joint Task Force (NCIJTF) and the Defense Collaborative Investigative Environment (DCISE). He lead the effort for malware analysis development at the DoD Cyber Crime Center and was the center’s first malware analyst. In these roles he was instrumental in guiding the process for malware analysis and cyber intelligence within the DoD LE/CI community. Mr. Upchurch is a former sworn law enforcement officer and has been conducting computer forensics professionally since 1999.</p>	

II.E.3.2 Dr. Anita D’Amico, AVI-Secure Decisions Key Person

Dr. Anita D’Amico, Director of Secure Decisions at Applied Visions, Inc.	
Proposed Role:	Principal Investigator
Proposed Level of Support:	10%
Education:	Ph.D. Psychology, Adelphi University, 1984 M.A. Psychology, Adelphi University, 1979 B.A. Psychology (major) Business (minor), University of Pennsylvania, 1973
Location:	Northport, NY
<p>Qualifications, experience, and relevance to program including certifications, awards, and recognition</p> <p>Dr. D’Amico is both a human factors psychologist and a specialist in information security situational awareness. Her research, publications, and teaching have been in the areas of: situational awareness, particularly improving decision-making through visualization; information security and information warfare; cognitive analysis; operational fatigue; and research methods. All Dr. D’Amico’s research projects stress the development of visualizations that can be rapidly transitioned into real operational environments for real-world evaluation and early adoption.</p> <p>She recently completed a cognitive task analysis of information security analysts in the DoD – the most comprehensive study of this population to date. The results of that work were used to design a new information security analyst’s decision tool incorporating multiple coordinated visualizations embedded in a user interface designed specifically for information security analysts.</p> <p>She is currently serving as the Principal Investigator on a project to visually represent the location, security state, mission and social network activity of wireless, mobile computing assets. Her prior work was nominated</p>	

twice for best Small Business Innovative Research of the year by a DOD agency.

Dr. D’Amico is past President of the Long Island Chapter of the Human Factors Society, as well as a member of the Board of Directors of the New York Chapter of the Information Security Systems Association (ISSA), which has over 500 members with expertise in information security.

Prior to joining Applied Visions, she was the founder and head of Information Warfare at Northrop Grumman. She led a major activity to develop a system for forecasting coordinated cyber attacks on military networks. She also led an Electronic Industries Association study of future Information Warfare tactics to be used in 2010 warfare. From 1989 to 1995 Dr. D’Amico was the Assistant Director of Research at Grumman Data Systems, where she led research activities on digital cartography and image processing applied to C2 and intelligence workstations.

Areas of Specialization: Situational awareness, particularly improving decision-making through visualization; human factors; information security; and experimental psychology.

II.E.3.3 Greg Hoglund, HBGary Federal Key Person

Greg Hoglund, Chief Executive Officer at HBGary, Inc.	
Proposed Role:	Principal Investigator
Proposed Level of Support:	10%
Location:	Sacramento, California

Mr. Hoglund is a world renowned cyber security and Windows internals expert. He architected HBGary’s commercial cyber security software products Digital DNA, Responder and REcon. Mr. Hoglund has published many significant works in the cyber security field:

- Rootkits: Subverting the Windows Kernel, Addison Wesley, 2005
- Exploiting Software: How to Break Code, Addison Wesley, 2004
- Exploiting Online Games, Addison Wesley, 2007
- “Hacking World of Warcraft: An Exercise in Advanced Rootkit Design,” BlackHat 2005/2006 USA/Europe/Asia
- “VICE - Catch the Hookers!,” BlackHat 2004 USA
- “Runtime Decompilation,” BlackHat Windows Security 2003 Asia
- “Exploiting Parsing Vulnerabilities,” BlackHat 2002 USA/Asia
- “Application Testing Through Fault Injection Techniques,” BlackHat Windows Security 2002 USA/Asia
- “Kernel Mode Rootkits,” BlackHat 2001 USA/Europe/Asia
- “Advanced Buffer Overflow Techniques,” BlackHat 2000 USA/Asia
- “A *REAL* NT Rootkit, patching the NT Kernel,” 1999, Phrack magazine

Mr. Hoglund pioneered new technologies to automatically reverse engineer software binaries from within computer memory and technologies to automatically harvest malware behaviors during its execution. He created and documented the first Windows kernel rootkit, owns the rootkit forum (<http://www.rootkit.com>) and created a popular training program “Offensive Aspects of Rootkit Technology.” Mr. Hoglund has mastery in software design and development, software reverse engineering, network protocols, network programming, and packet parsing. He is fluent and highly experience with developing Windows device drivers, debuggers and disassemblers. Prior to founding HBGary, Mr. Hoglund was founder and CTO of Cenzie where he developed Hailstorm, a software fault injection test tool.

II.E.3.4 Phillip Porras, SRI International Key Person**Phillip Porras, Program Director of Systems Security Research at SRI International**

Proposed Role:	Principal Investigator
Proposed Level of Support:	25%
Education:	M.S. Computer Science
Location:	Menlo Park, California
<p>Mr. Porras is a Program Director of systems security research in the Computer Science Laboratory at SRI International, and has been a Principal Investigator for many research projects sponsored by DARPA, DoD, NSF, NSA, and others. He is currently a Principal Investigator in a multi-organization NSF research project, entitled "Logic and Data Flow Extraction for Live and Informed Malware Execution." He leads a research project studying malware pandemics on next generation networks for the Office of Naval Research. He is also the Principal Investigator of a large ARO-sponsored research program entitled Cyber-TA, which is developing new techniques to gather and analyze large-scale malware threat intelligence across the Internet. Mr. Porras' most recent research prototype technologies include BotHunter (http://www.bothunter.net), BLADE (ww.blade-defender.org), Highly Predictive Blacklists (http://www.cyber-ta.org/releases/HPB/), and the Eureka malware unpacking system (eureka.cyber-ta.org). He has been an active researcher, publishing and conducting technology development in intrusion detection, alarm correlation, malware analysis, active networks, and wireless security. Previously, he was a manager in the Trusted Computer Systems Department of the Aerospace Corporation, where he was also an experienced trusted product evaluator for NSA (which includes security testing, risk assessment, and penetration testing of systems and networks). Mr. Porras has participated on numerous program committees and editorial boards, and on multiple commercial company technical advisory boards. He holds eight U.S. patents, and have been awarded Best Paper honors in 1995, 1999, and 2008.</p>	

II.E.3.5 Andrew Tappert, Pikeworks Key Person**Andrew Tappert, Research Engineer at Pikeworks**

Proposed Role:	Principal Investigator
Proposed Level of Support:	100%
Education:	B.S. Information Technology, University of Miami, 2002 M.S. Computer Science, Stanford University, 2006
Location:	Alexandria, Virginia
<p>Mr. Tappert has nine years of experience with rootkits, malware, and other kernel/low-level software development efforts. He has served as the technical lead responsible for the development of the only commercially available memory analysis and malware detector for the Linux operating system. Mr. Tappert has performed computer security research and software development in government, industry, and academia. As an undergraduate at the University of Miami in Coral Gables, Florida, his senior project, completed under the supervision of Dr. Stephen Murrell of the department of Electrical and Computer Engineering, was entitled "Construction and Operation of a Honeypot; Analysis and Mitigation of an Internet Worm thereby Discovered." While pursuing his undergraduate degree, Mr. Tappert began working at the Central Intelligence Agency as a co-op. In the CIA's Information Operations Center, he did cutting-edge work on software security technology, among other things developing a novel technique for modifying a running Linux kernel. For his accomplishments at the CIA he was honored with an Exceptional Performance Award.</p> <p>After graduating from the University of Miami, Mr. Tappert was accepted to the Master's degree program of Stanford University's Computer Science department. At Stanford, he specialized in Software Theory, deepening his knowledge of many aspects of computer science. Among the courses he took was "Security Analysis of Network Protocols," for which he and a classmate developed a temporal logic model to analyze an</p>	

“Anonymous Fair Exchange E-Commerce Protocol” that had recently been published. They discovered several flaws in it, which were later cited in “An Improved E-Commerce Protocol for Fair Exchange” by other authors.

Mr. Tappert has also written white papers on hot topics and current research in computer security, including an analysis of the progress and potential of trusted computing based on the TCPA/TCG specifications for a “trusted platform module” (TPM) chip.

Mr. Tappert is an experienced system-level developer and researcher who has researched and developed software security technology including techniques for modifying a running Linux kernel, methods for discovering kernel level rootkits, and designing and operating Honeypot systems. He is experienced programming in languages such as C, C++, Python, and PHP. He is also experienced using Linux specific debuggers and disassemblers like gdb and objdump.

II.E.3.6 Dr. Dawn Song, UC Berkeley Key Person

Dr. Dawn Song, Associate Professor at UC Berkeley

Proposed Role:	Principal Investigator
Proposed Level of Support:	20%
Education:	Ph.D. Computer Science, UC Berkeley, 2002
Location:	Berkeley, California

Dr. Song is an Associate Professor in the Electrical Engineering and Computer Science Department at the University of California, Berkeley. Prior to joining UC Berkeley, she was an Assistant Professor at Carnegie Mellon University from 2002 to 2007.

Dr. Song’s research interest lies in security and privacy issues in computer systems and networks, including areas ranging from software security, networking security, database security, distributed systems security, to applied cryptography.

Dr. Song is the recipient of various awards including the NSF CAREER Award, the Alfred P. Sloan Research Fellowship Award, the IBM Faculty Award, the George Tallman Ladd Research Award, and the Okawa Foundation Research Award. She is also the author of multiple award papers in top security conferences, including papers at the IEEE Symposium on Security and Privacy and the USENIX Security Symposium. Recently she was awarded the MIT Technology Review TR-35 Award, recognizing her as one of the world's top innovators under the age of 35.

Among other work, Dr. Song has been leading the project BitBlaze, a new infrastructure for binary analysis for security applications. It features a novel fusion of static and dynamic code analysis as well as model checking and theorem proving techniques to serve as the foundational machinery for in-depth understanding of vulnerabilities and attacks on them, and the design of effective defenses. It has also led to state-of-the-art technologies in malware analysis. Work in BitBlaze has led to Best Paper Awards in top security conferences. This infrastructure will be the first of its kind and aims to provide a foundation for other researchers and projects to build upon. It has already empowered new developments at more than a dozen research institutions, leading security and IT companies, as well as startups.

II.F Four-Slide Summary

GDAIS Cyber Genome Team

Vision
Innovative Claims

Our XX significant innovations resolve key technical gaps

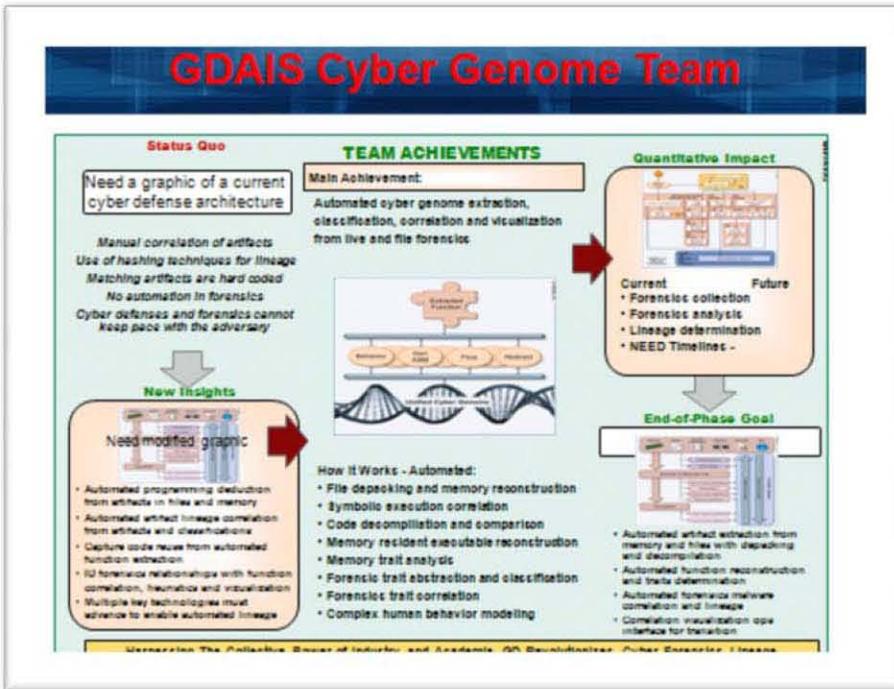
GDAIS Cyber Genome Team

Contract Proposal Specifics
IP
Data Rights
Deliverables

GDAIS-Cyber Genome Team

Phase 1	Period 1a (base)	\$##M	
	Period 1b (Option 1)	\$##M	
Total Phase 1			\$##M
Phase 2	Period 2a (Option 2)	\$##M	
	Period 2b (Option 3)	\$##M	
Total Phase 2			\$##M
Program Totals			\$##M

- **Proposed contract type [i.e. Cost Plus Fixed Fee (CPFF), Cost Plus Award Fee (CPAF), Cost Plus Incentive Fee (CPIF), Fixed Firm Price (FFP), etc.]**



III. Detailed Proposal Information

III.A SOW Tasks and Subtasks

Statement of Work (SOW) - In plain English, clearly define the technical tasks/subtasks to be performed, their durations, and dependencies among them. For each task/subtask, provide:

- A general description of the objective (for each defined task/activity);
- A detailed description of the approach to be taken to accomplish each defined task/activity);
- Identification of the primary organization responsible for task execution (prime, sub, team member, by name, etc.);
- The completion criteria for each task/activity - a product, event or milestone that defines its completion.
- Define all deliverables (reporting, data, reports, software, etc.) to be provided to the Government in support of the proposed research tasks/activities.

III.B Description of Results, Products, Transferable Technology, and Transfer Path

Description of the results, products, transferable technology, and expected technology transfer path enhancing that of Section II B.

III.C Detailed Technical Rationale

Useful cyber genetics to understand cyber lineage relies on capturing code reuse in software, finding relationships, weighting those relationships with contextual information, and providing a method to understand those relationships. Code reuse is best captured by extracting functions from code. Identifying relationships between software samples is accomplished by correlating extracted functions with others extracted from differing samples. The context of correlations is best captured by identifying relationships of critical value, such functions that achieve malicious behavior, identifying relationships of little value, such as common functions seen in legitimate behavior, and understanding and capturing multiple correlations that share proximity to capture code reuse that spans simple functions. Finally, to understand how these relationships are important to a specific application, such as cyber intelligence gathering, methods to interface with the system must be provided.

Revolutionary Change
in Methods of
Correlation is
Required for Cyber
Lineage

Capturing Code Reuse through Function Extraction

It is the reuse of computer code that creates lineage information; therefore, efforts to understand this lineage should be based on identifying that code. Efforts so far in creating lineage trees have been lacking. They have relied upon arbitrary alignment of code or artificial boundaries of code segments. Such approaches are very effective if code length and position are defined, such as that with biological genomes. However, cyber code varies in length and has boundaries that vary in position; therefore boundaries must be defined intelligently. Defining code segments by

function boundaries achieves this goal.

Lineage detection must be based on code reuse; the basis for cyber lineage

By using extracted functions from de-obfuscated programs, cyber genomes can be created intelligently. Cyber genomes created in this way can reflect not just a statistical mapping of a program, but reflect the content of the program. Genomes based on extracted functions do not suffer from alignment issues, as intelligent boundaries, based on defined functions, self align. Of course, meaningful functions can only be extracted from viewable code, so de-obfuscation is a must in the process.

Human understanding of computer code is a great advantage in mapping a cyber genome and its correlation. By basing correlation on a genome comprised of extracted functions, the genome itself can be manipulated (or viewed) to encourage correlation. Intelligent manipulation of instantiated machine code of an extracted function can be used to remove specifics that are not reflected in source code. It is our understanding of computer instructions combined with extracted functions that allow for these methods.

Identifying Relationships through Function Correlation

Function correlation provides relationships for use in lineage as it reflects the reuse of code in multiple programs. Correlation can occur through statistical, Bayesian, and exact matching from areas of general mathematical correlation and more specific areas of the science where the information set as a whole shares significant similarities.

Function Correlation Reflects Code Reuse

Correlation should not be conducted context free. While reliable context free correlation would show lineage, it would be limited in its use. Particular traits, such as malicious logic within malware, are of much greater importance than common software code reuse such as a command line parser. While unique implementation of common functionality would be of interest, function correlation common across the broad spectrum of software is not. Methods for weighting correlations of higher interest and lower interest should be incorporated into any lineage system.

Context Gives Meaning to Correlation

In addition to these functional weights, proximity of multiple correlations is also of high importance. Code reuse is not limited to single functions and a reuse of a code snippet that contains multiple functions needs to be captured. Such captures will allow for greater confidence of correlation and lineage. Any lineage attempt based on function extractions should account for proximity to other correlated functions.

Understanding Complex Relationships through Heuristics and Visualization

Such a lineage scheme is likely to generate huge amounts of information. Heuristics should be used to limit the amount of information that has to be both computed and stored. Even so, there is likely to be a very large amount of information that needs to be accessed and understood by both malware experts and cyber intelligence/law enforcement personnel. An interface designed for such a system is critical to its usefulness.

III.D Detailed Technical Approach and Plan

III.D.1 Researching Cyber Genetic Lineage

The goal is to create meaningful correlation of extracted functions from malware. From those correlations, it will be possible to traverse and examine relationships; however, to accomplish correlation, research into a variety of correlation algorithms must be conducted to examine their applicability in this information space.

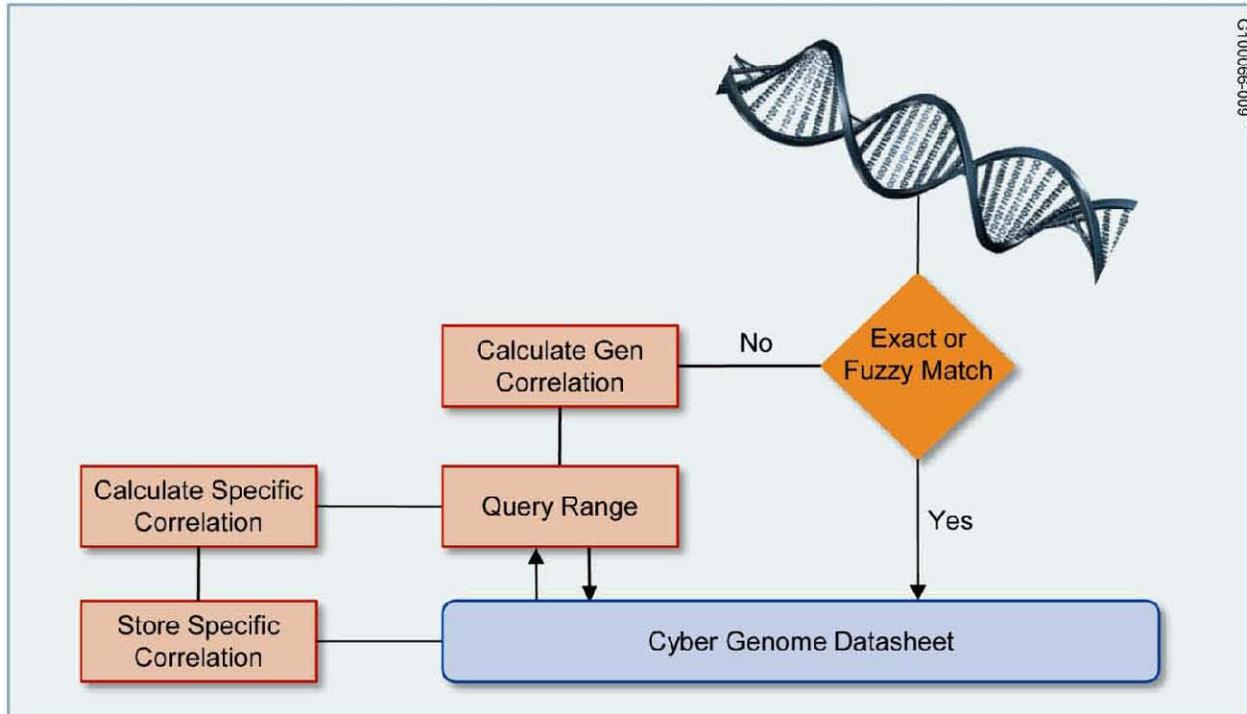


Figure 5. Researching Cyber Genetic Lineage

III.D.1.1 Correlation Algorithms

Our team intends to study both physical and Bayesian probabilistic approaches to the problem, incorporating knowledge gained through prior computational correlation work, including those in biological genome lineage and correlation. We will begin by studying how well these algorithms perform against function extractions from controlled source. We will introduce variance in the extracted functions, studying how differing variances effect correlation. The variances themselves will be produced through manual manipulation of extracted functions, compiler option changes, code position changes, and by rotating through numerous compilers. Correlation algorithm(s) selection will be accomplished on the results of this work. Those algorithms will be used against known samples of extracted functions to establish thresholds of probability of correlation.

Establishing specific correlation in this way is computationally expensive. It requires all functions to be compared to all other functions. For each order of magnitude increase in functions, roughly two orders of magnitudes of correlations need to be computed and stored. In the research environment, this is overcome by the relatively small number of samples being processed. However, for this research to be a viable candidate for transition, the volume of

correlation computations needs to be limited.

III.D.1.2 Heuristic Correlation

To limit the amount of computational overhead involved in correlation, we intend to study how general correlation can be applied to the problem. Our hypothesis is that measurable properties of extracted functions directly correlate to the probability of specific correlation between functions. These properties include entropy, entropy maps, and frequency analysis. Such properties can be measured without direct comparison with other functions and therefore have a linear computational and storage profile. This allows for a heuristic approach to examine relationships between functions, and therefore the malware, that will overcome future scalability problems with the technology. We will examine the relationships between specific correlation values for each of the studied algorithms used to provide specific correlation with the general statistical properties of each. This study will prove or disprove this relationship and establish thresholds that can be used to control the number of specific correlation calculations.

III.D.2 Researching Cyber Genome Mapping

In addition to heuristics, correlation can be encouraged through manipulation of the functions themselves. Exact function matches do not need correlation algorithms applied and can be handled through traditional relational algorithms. Therefore, how function information is normalized is critical to the functionality of correlation research. We intend to examine two approaches to function normalization: the scrubbing of traditional ASM/machine language extractions and the use of function abstraction.

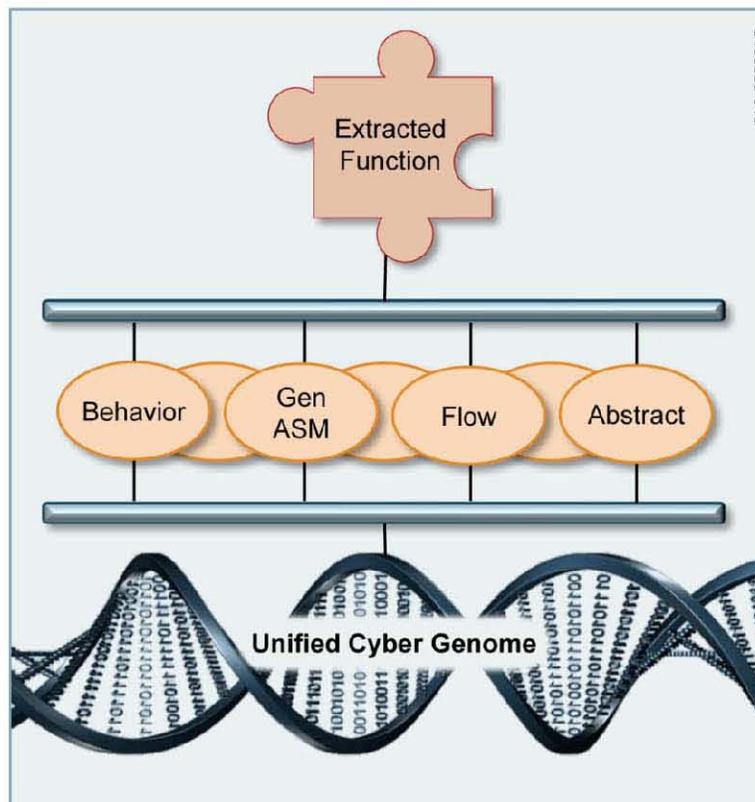


Figure 6. Researching Cyber Genome Mapping

III.D.2.1 ASM/Machine Code Genomes

Extracted functions in their raw form exist as machine code. Depending on the extraction technique, they also may be represented as ASM code; however, there is ASM and machine op codes are directly interchangeable and therefore it is immaterial which is used for correlation. However, specific instantiations of machine code compiled from source is largely dependent on the compiler methods. Even if the compiler remains static, arrangement of functions within code can provide variances in specific registers used to execute code as well as the changes in referenced memory addresses and other information calculated during compilation. To encourage exact matching of functions represented in ASM/machine code, these types of variations need to be obscured.

We intend to study how to create function representations that have compile time variances obscured. Our process is consist of researching compiler output vs. a controlled input to determine what information needs to be obscured from the function representation. We recognize this approach may have limits with respect to compiler optimizations and cross compiler compilations and the scrubbing process used to obscure compile time variances reduces correlation reliability. However, we intend to examine this ASM/machine code method concurrently with a method to abstract functions.

III.D.2.2 Abstract Views of Genomes

Machine code generated by wholly different compilers can be quite dissimilar. The manipulation of the stack in GCC is much different than that in MS Visual C. Therefore attempts at cross compiler correlation are not likely to be fruitful if function representations are based on ASM/machine code. Ideally, code comparisons would be conducted with source code exclusively; however, source code is rarely available for such comparisons. However, advances in de-compilation do provide techniques that allow for the next best thing to source code.

Our goal is not to use human readable de-compilation as a basis for function representation, but to use techniques in creating de-compilation, such as intermediate languages, to abstract functions from compiler specific methods. The function abstraction process removes all compiler specific manipulations of the stack, registers, memory, comparison operators, jump operators, etc. The result is a function representation that abstracted to the point it that cross compilation comparisons becomes possible without scrubbing.

III.D.2.3 Correlation Weight

Function correlations in and of themselves provide relationships between their corresponding programs, but no context on why those relationships are important. Functions that are malicious in purpose are likely to be more important than those that are not. Functions that are common across many or most programs, such as loaders, API calls, etc do not show meaningful correlation at all. Additionally, several functions correlated between programs that are adjacent in both programs suggest a much stronger correlation than those that are spread across their respective programs. Therefore, when creating a correlation schema to examine malicious software lineage, a context free lineage of functions is of limited use and metadata that captures function behavior and control context is critically important.

III.D.2.4 Finding Correlations of Elevated Importance

Malicious behavioral information can be captured through traditional trait analysis. However, the technology as it exists today is not function boundary aware. It is not enough to identify if a

program contains malicious or potentially malicious behaviors as correlation is based not upon program wide correlation, but function correlation. The technology will need to be modified to indicate which specific function initiates the malicious behavior. That information will be tied to the function representation and used to weight relationships more heavily.

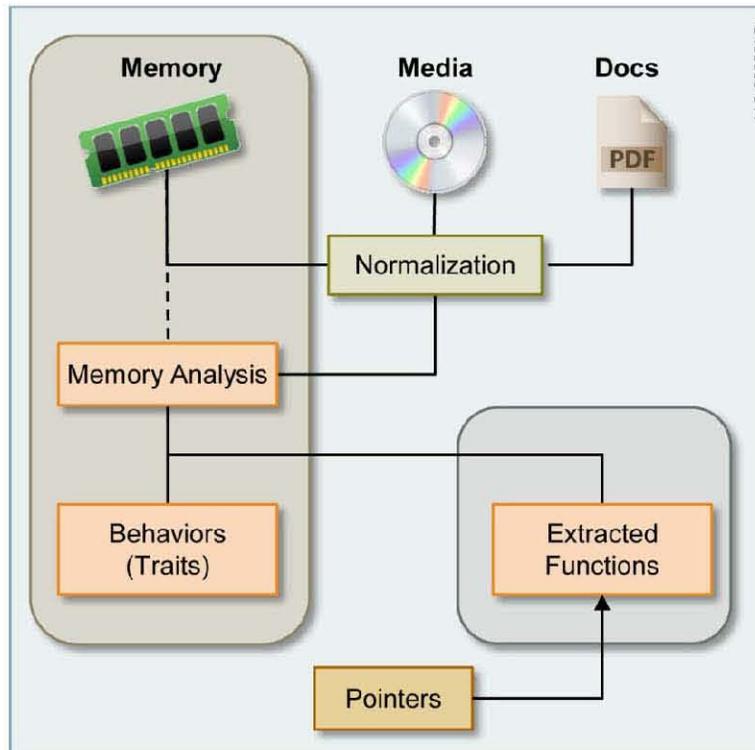


Figure 7. Finding Correlations of Elevated Importance

III.D.2.5 Finding Irrelevant Correlations

Conversely, functions that common to many programs and of no significant importance can be identified through frequency analysis of correlation in programs known not to be malicious. The correlation research itself will provide the engine to generate correlations that are not of significant value. By processing non-malicious software exclusively originating from a wide breath of authors, significant correlations should be extracted and weighted more lightly. When these function signatures are compared against malware or suspected malware, cross malware function relationships that also correlate to these known functions would be weighted lightly.

III.D.2.6 Control Flow as Context

Code reuse, which is the basis of lineage in software, is not limited to functions only. . Often large code segments are extracted to achieve specific functionality. These blocks represent functions, loops, or control code that calls other functions. Control flow information links how functions are interrelated and can be captured by examining full execution path control flow of compiled binaries and linking functions to their calling parent or called child. This interaction is important in correlation, just as proper genome alignment is vital to biological correlation. Our approach incorporates function interaction by examining and incorporating control flow information into the cyber genome. Function interaction will be extracted from control flow

information and stored as metadata in the cyber genome.

By capturing function interrelation within program logic, multiple function correlation within samples of malware or other software can be weighted by adjacency. Multiple functions that are correlated between program samples that also adjacent in both samples are likely to be much more relevant than those that are not.

III.D.3 Automating Function Extraction

In our solution, correlation cannot be achieved without function representations, which cannot be achieved outside of the laboratory without a method to extract functions from compiled programs in mass. We intend to pursue two methods for function extraction from code that is not obfuscated: linear execution and full execution space extraction.

III.D.3.1 Linear Execution Extraction

The most simple and widely used method used to access functional code in malware is linear execution. Widely used in simple dynamic analysis, it is also used in execution tracing and memory trait examination to determine software behavior. It gives access to code as it is called and often de-obfuscates full program functionality prior to functional execution. However, this method is so far limited in practical use. Executables that require certain runtime or software dependencies, such as specific locations or command line options, or dll's that need injected into certain processes or called by other executions usually require manual examination prior to execution. For automation to occur, this process needs to be studied and solidified.

Linear execution extraction will be accomplished by extracting functions from memory while the code is executed. We will locate the process in memory and extract its process space. Function boundaries will be located through common disassembly methods. At this time we will also conduct trait analysis to determine functions that contain known malicious behavior. We will extract functions and metadata of any corresponding malicious behavior. This data, of course, will be used to obtain function representations for use in correlation.

III.D.3.2 Full Execution Space Extraction

Conversely, full execution space function extraction does not require examination of runtime requirements prior to execution; however, it is often limited by obfuscation. Obfuscation is very common in malicious software. It is often implemented through post compilation binary packing/obfuscation software that inhibits examination. Automation from this perspective requires de-obfuscation/unpacking and techniques to bypass or remove anti-analysis and other suicide logic.

Full execution space extraction will be accomplished by fully exploring the execution space of compiled code that is not obfuscated. Traditional static techniques for disassembly and University of California at Berkeley's symbolic execution technique will be used to gain access to code that is not accessible in simple linear execution. Again, disassembly techniques will define function boundaries for function extraction. However, trait behavior analysis may be somewhat limited in this case.

III.D.3.3 Normalization and Preparation: De-Obfuscation

Code obfuscation is very common in malicious software, particularly the use of packers. Any attempt at creating a cyber lineage solution that can be transitioned must deal with automated methods for de-obfuscating malicious software. Without such techniques, gaining access to

functions en masse to create a viable cyber genome is not possible. Our team has brought together University of California at Berkley and SRI to extend this research. Both have significant research in this area that has lead to working concept prototypes that extract meaningful code. In addition, de-compilation research conducted by SRI has shown promising results in detecting obfuscated code that is not necessarily packed and therefore is difficult to detect in automation through statistical tests. This method will provide a much needed litmus test in the unpacking process. However, further research in automation is needed to ensure their methods for de-obfuscating code will produce a viable end product, including locating the original entry point (OEP), rebuilding the imports table, and rebuilding the extracted code to a working executable.

III.D.3.4 Normalization and Preparation: Executable Reconstruction

Closely related to de-obfuscation is the reconstruction of code extracted from memory. These two areas share similar problems, such as locating the OEP and rebuilding the imports table. SRI will use existing methods for locating the OEP and rebuilding the imports table manual and study how to reproduce those manual efforts in automation. In addition, memory addresses and segmented code will be dealt with in a similar fashion.

III.D.3.5 Normalization and Preparation: Suicide and Anti-Analysis Removal

Traits, signatures, and even the lineage system itself will be used to detect anti-analysis logic that results program suicide. Such logic is often reused and the design of the project is geared toward detect just this sort of reuse. After detection, the logic will be isolated through function boundaries and removed or disabled. The resulting program will be free from suicide logic that attempts to foil analysis.

III.D.3.6 Normalization and Preparation: Encapsulated Malicious Logic

Malicious logic can be, and frequently is, encapsulated in exploit code. Though this exploit code is itself of interests, locating and examining the exploits payload often yields more useful results. However, triggering the exploit to push its payload is often a cumbersome process of manipulating the environment to ensure the exploit function properly. We intend to research methods of locating embedded logic within Microsoft and PDF documents. GDAIS's role as malware analyst within the government has already produced results in both locating and extracting malware in such documents. Research will be focused on automation of these manual processes.

III.D.3.7 Normalization and Preparation: Trigger Analysis

Dynamic analysis and execution tracing is dependent on successful execution of malware. Successful execution requires both then environment and parameters at the time of execution be correct. However, regardless of successful execution (that is execution that produces meaningful observations), execution does occur. An examination of program logic that triggers behavior has been researched by the University of California at Berkley as a part of their symbolic execution research. We intend to apply this method to identify runtime requirements of malware to produce malicious activity.

III.D.3.8 Normalization and Preparation: Automated Execution

Once the malware has been normalized or prepared for execution, though one or a combination of de-obfuscation, reconstruction, suicide logic removal, and extraction; and runtime requirements have been identified, automation of execution can occur. We intend for this

automation of execution to load the malware into memory for linear execution and load into static tools to accomplish full execution space extraction. The basis of normalization, preparation, and automated execution will provide data for the correlation process to begin. It is necessary to achieve transition of the technology.

III.D.4 Visualization

A viable correlation dataset will have vast amounts of information even with heuristics and genome manipulation to reduce the amount of stored results. It is envisioned that lineage could encompass hundreds of relationships of various weights for each sample that correlate that malware samples to others. Simple text based results would require significant time and expertise in the lineage systems internal workings to understand. Similarly, querying results in a textual format would produce similar lack luster results.

As such, our approach is to design the dataset and relationships from the ground up with visualization in mind. Secure Decisions will work with other team members from the beginning of the project, particularly with dataset and correlation researchers, to design a system that will have end user technical limitations and use cases in mind.

The visualization system will allow users to examine relationships starting from a particular sample or examine over all trends in relationships, such as most commonly used code weighted with contextual information. Users will be able to navigate correlations within the lineage dataset from one sample to another, examine the values used to determine relationships, view relationship strengths visually, and extract code location for manual examination.

III.E Existing Research Comparison

Comparison with other ongoing research indicating advantages and disadvantages of the proposed effort.

III.F Previous Accomplishments

GDAIS and our team has successfully executed numerous contracts for the federal government and the Department of Defense (DoD). We have selected the contracts for our corporate experience to demonstrate that the GDAIS team has the experience to perform the work required by DARPA for the Cyber Genome Program within budget and on time. We are submitting one contract experience citation from each participating team member for your consideration that are described in detail in subsequent sections. These contracts are summarized in Figure 8.

Figure 8. Summary of Previous Accomplishments

Contract Name	Contractor
Defense Cyber Crime Center (DC3)	GDAIS
VIAssist (AFRL / IARPA / NSA)	AVI-Secure Decisions
DHS Science and Technology Directorate (STD)	HBGary Federal
Army Research Office Cyber-TA	SRI International
AFRL Anti-Forensics	Pikewerks
NSF / DoD BitBlaze	UCBerkeley

III.F.1 Past Performances**III.F.1.1 GDAIS Past Performance**

GDAIS has been the prime contractor for the Defense Computer Forensics Laboratory (DCFL) for over eight years. We worked alongside Government and Military personnel to form, evolve, and mature DC3 into the premier digital forensics laboratory in the nation.

Offeror Name: GDAIS	Customer Organization: Defense Cyber Crime Center (DC3)	
Program Manager: Mike Buratowski	Address: 911 Elkridge Landing Road, Linthicum, MD 21090	
	Phone Number: 410-981-0117	
Contracting Officer: Jim Hayes	Address: 2100 Crystal Drive, Suite 300, Arlington, VA 22202	
	Phone Number: 703-605-3600	
Contract Type: T&M	Contract Value: \$98M	PoP: Oct 2001 – Feb 2012

Description of Worked Performed

Department of Defense Cyber Crime Center (DC3) is a \$126M multi-year T&M contract in support of the Air Force Office of Special Investigations (AFOSI). Since 2001, the GD Team has been the prime contractor for the Department of Defense Computer Forensics Laboratory (DCFL). In this capacity, the GD Team has conducted extensive network intrusion examinations and generated detailed reports documenting the intrusions. The DCFL, and DoD Cyber Crime Institute (DCCI) all fall under this contract.

Business Relationships & Customer Satisfaction: The GD management team provided the leadership that organized, planned, and managed the resources for the contract's major projects. Since careers and legal convictions are dependent upon our findings, we insist on the highest standards of quality and cross-check. The GD Team is tightly integrated with the DC3 workforce of Government and Military personnel and work as equals in all facets of forensic support. The GD Team provides onsite program management at the DC3 for all contractor and subcontractor work. The Program Manager manages a staff of 140 personnel consisting of General Dynamics engineers, technicians, support personnel, and subcontractors. In March 2007, General Dynamics was awarded a new, 1-year (plus four option years) contract to provide Computer Forensic Examination support as well as Research, Development, Testing and Evaluation for computer forensic hardware and software.

Cost, Schedule & Timeliness: The GD Team has exceeded Government expectations by completing over 2,500 examinations, providing expert testimony in over 100 court proceedings (both CONUS and OCONUS), and serving as the DoD authority on electronic media forensics. DC3 Incident Response Support has experience with responses involving single system through large networks with enormous data storage capabilities. In its role, the GD Team has created a Virtual Analysis Environment where various system configurations including installed software packages and patch levels are already saved as Virtual Machines. The examiner can execute the known malicious logic within a system that is configured exactly how the compromised system would have been at the time of an intrusion.

Key Personnel: The GD Team accounts for over 80 percent of the personnel that perform data recovery, imaging and extraction, and forensic examinations in support of criminal, fraud, counterintelligence, data recovery, terrorism, and safety investigations in DC3. The team currently consists of 19 Cyber Intelligence Analysts, 13 Forensic Technicians, 48 Forensic Examiners, 15 Software Developers, and 5 Forensic Managers that perform casework for DC3.

Relevance to DCG Technical Area 1

This program has provided GDAIS with the operational knowledge and expertise of the latest intrusions and

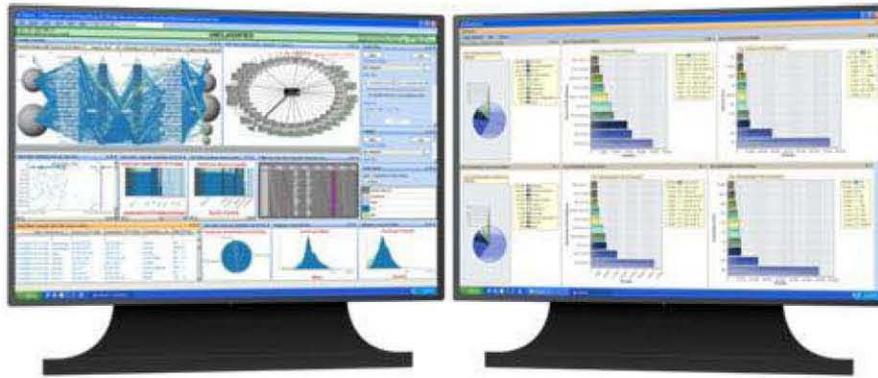
cyber threats seeing in DoD and Defense Industrial Base networks. In turn, it has provided GDAIS with the capabilities and knowledge to detect these cyber threats and their artifacts by using many of the forensics and reverse engineering capabilities within our analysis and R&D team. Since the number of intrusion cases has increase exponentially at DC3, we had the need to start performing automated behavior analysis and correlation between malware binaries. Within the DCFL/Intrusions Section, our engineers and computer scientist are developing a capability to automatically correlate these malicious binaries against malware found in previous intrusion cases. This is done with the use of IDA Pro and various fuzzy hashing techniques to disassemble the malicious binaries into individual function and perform correlation against the malware obtained through the many different intrusion cases. By using open source, freeware, and government sponsored tools they have also developed a capability to submit malicious binaries to perform automated behavioral analysis. This is the type of capabilities that together with our vast knowledge of the latest intrusions, GDAIS could leverage and enhanced for the DARPA Cyber Genome program. From the DCFL/NCIJTF perspective, our intelligence analysts use the analysis report generated by our DCFL/IA examiners to perform additional correlation against various events and data. Once this is done, reports and signatures (intrusion indicators) are distributed to the community. The DCCI R&D team is constantly collaborating with different DoD, academia, and industry organization to learn about their effort and share tools for addition into our DC3 operations. Many of these tools are tested and validated by our DCCI T&E team to verify that the results are accurate and reliable.

For technical area one of the DARPA Cyber Genome program, GDAIS, together with their partners, will employ revolutionary techniques to exploits our collective knowledge and expertise to automatically ingest these malicious binaries and provide correlation, lineage, and provenance in order to gain a better understanding of software evolution, detect zero-day malware, and when possible determine attribution.

III.F.1.2 AVI-Secure Decisions Past Performance

Offeror Name: AVI-Secure Decisions	Customer Organization: AFRL / IARPA / NSA	
Program Manager: Walter Tirenin	Address: 525 Brooks Road, Rome, NY 13441	
	Phone Number: 315-330-1871	
Contracting Officer: Rebecca Willsey	Address: 26 Electronics Parkway, Rome, NY 13441	
	Phone Number: 315-330-4710	
Contract Type: BAA	Contract Value: \$2.3M	PoP: Sep 2005 – Dec 2008
Description of Worked Performed		

VIAssist is a visualization framework used by computer security specialists to ensure the security of computer networks. It was developed to visualize NetFlow data, and is currently used by the intelligence community and being modified for adoption by DHS for the US-CERT. In addition to NetFlow data, VIAssist can visualize intrusion detection and other data sources. VIAssist converts network data into a collection of graphical representations to make it easier to see patterns and trends. This technique takes advantage of the innate ability of humans to perceive patterns in pictures that they might otherwise miss when looking at raw data.



What makes VIAssist’s suite of integrated tools unique is how the component visualizations work together synergistically. VIAssist’s value is in presenting several visualizations at once, and synchronizing them to a single common data source.

VIAssist’s Smart Aggregation and filtering capabilities address scalability issues, and its rich

report-generating capability allows analysts to create comprehensive written reports and PowerPoint presentations to effectively communicate findings with colleagues and supervisors. VIAssist’s strengths lie in its ability to:

Provide global & detailed situational awareness. Dual monitor displays provide a global, summarized view of the rise, as well as a focused view of specific incidents.

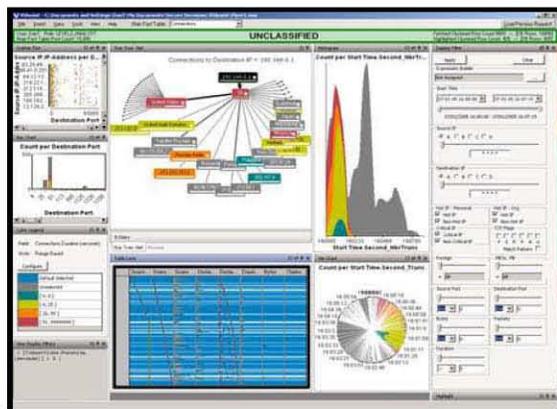
Provide multiple views of the same data. Multiple coordinated views of the data are provided to make it easier to identify anomalies, relationships and interdependencies between data points.

Correlate multiple data sources. Using an intermediary data store, VIAssist can integrate with and visualize multiple disparate data sources, such as firewall logs, IDS data and NetFlow data.

Aggregate data. Through the use of Smart Aggregation technology, VIAssist has the ability to effectively display voluminous data by visually aggregating data into meaningful visualizations with drill-down capability and in so doing, reduce load on system and response time.

Filter data. Through the use of an advanced Expression Builder VIAssist can filter data based upon various pre-defined or complex user-defined criteria, allowing analysts to focus on specific data, to the exclusion of the mass of “noise” that can often obscure security risks.

VIAssist was named one of the top ten technologies of CWID 2006. It is a mature product at TRL 8.



Provide workflow continuity & collaboration. With VIADiary analysts can record observations. Shared annotations allow users to collaborate with colleagues about their findings.

Provide effective reporting. Through the use of the Report Designer and pre-defined report templates, VIAssist streamlines report building and reduces the likelihood of data transfer errors.

Provide spatial context. By 2009, VIAssist will include geographical visualizations, global and local network topological visualization components, as well as the augmentation of

expression-building capability to help analysts improve their understanding of network security activity.

Relevance to DCG Technical Area 1

Specific technologies developed for VIAssist that support smart data aggregation may be leveraged to assist in providing compelling and scalable visualizations to support malware analysis.

III.F.1.3 HBGary Federal Past Performance

Offeror Name: HBGary Federal	Customer Organization: DHS Science and Technology Directorate	
Program Manager: Douglas Maughan	Address: 1120 Vermont Ave NW 8th Floor, Washington, DC 20528	
	Phone Number: 202-254-6145	
Contracting Officer: Doreen Vera-Cross	Address: P.O. Box 12924, Fort Huachuca, AZ 85670	
	Phone Number: 520-533-8993	
Contract Type: SBIR Phase II	Contract Value: \$975,000	Dec 2007 – Nov 2010
Description of Worked Performed		
Relevance to DCG Technical Area 1		

III.F.1.4 SRI International Past Performance

Offeror Name: SRI International	Customer Organization: Army Research Office	
Program Manager: Cliff Wang	Address: 4300 S. Miami Blvd, Durham, NC 27703	
	Phone Number: 919-549-4207	
Contracting Officer: Kathy Terry	Address: P.O. Box 12211, Research Triangle, NC 27709	
	Phone Number: 919-549-4337	
Contract Type: Grant	Contract Value: \$13.4M	PoP: Jun 2006 – Jul 2010
Description of Worked Performed		
<p>Phillip Porras is the Principal Investigator of the Army Research Office sponsored Cyber-TA Project. Cyber-TA is an ongoing 5-year research project to develop the next-generation of real-time national-scale Internet-threat analysis technologies. Our team has developed many new sophisticated antimalware and malware tracking technologies, produced over 50 publications in scientific peer reviewed venues, and has deployed its technologies widely across DoD and the U.S. Government. The Cyber-TA research project has brought together many of the world’s most established researchers across the fields of data privacy, cryptography, malware and intrusion detection research, as well as operational experts in Internet-scale sensor management, to develop leading edge solutions to the evolving threat of increasingly virulent and wide-spread self-propagating malicious software. Examples of Cyber-TA research technologies include:</p> <ul style="list-style-type: none"> • Eureka – A binary unpacking and decompilation system designed to overcome a broad spectrum of malware binary logic protection services: http://eureka.cyber-ta.org • BLADE – A system to immunize Windows platforms from malicious drive-by malware exploits: http://www.blade-defender.org 		

- Highly Predictive Blacklists – A link-analysis-based IP blacklist production system for producing high-quality network blacklists: <http://www.cyber-ta.org/releases/HPB/>
- BotHunter – A network-based host infection diagnosis system: <http://www.bothunter.net/>
- Malware Threat Center – A portal for tracking Internet malware threats across the Internet: <http://mtc.sri.com>
- Malware Cluster Lab – An example of SRI’s experience in applying malware forensic clustering to detect malware binary lineage is available at <http://cgi.mtc.sri.com/Cluster-Lab/>, and an example of our ability to conduct a quantifiable comparison of pair-wise binary logic within two malware binary samples that employ multi-layered packing is available at http://mtc.sri.com/Conficker/addendumC/HMA_Compare_ConfB2_ConfC/.

A Cyber-TA project overview description is available at: http://www.cyber-ta.org/pubs/IEEE-SnP-Magazine-CTA_Nov2006.pdf

Relevance to DCG Technical Area 1

Cyber-TA has provided an ongoing resource for SRI’s Computer Science Laboratory to conduct both breadth and depth research in understanding and combating the modern Internet crimeware epidemic. Of particular relevance to DCG is the extensive Cyber-TA research that our team has produced in the area of binary unpacking, disassembly, decompilation, and deobfuscation. We have demonstrated our advanced deobfuscation techniques in work such as (<http://mtc.sri.com/Conficker/P2P/index.html>), which is to our knowledge the only published description of the multi-layered obfuscated code base of the Conficker P2P subsystem. An example of our ability to handle mobile malware binary reverse engineering on non-x86 binaries is available at <http://mtc.sri.com/iPhone/>.

III.F.1.5 Pikewerks Past Performance

Offeror Name: Pikewerks	Customer Organization: Air Force Research Laboratory	
Program Manager: Dr. David Kapp	Address: 2310 Eighth Street, Bldg 167, Wright-Patterson AFB, OH 45433	
	Phone Number: 937-320-9068 x130	
Contracting Officer: Erika Lindsey	Address: 2310 Eighth Street, Bldg 167, Wright-Patterson AFB, OH 45433	
	Phone Number: 937-255-3379	
Contract Type: CPFF	Contract Value: \$750,000	PoP: Aug 2008 – Aug 2010

Description of Work Performed

Anti-Forensics is the art and practice of obscuring data storage, transmission, and execution in such a way that it remains hidden from even a professional, dedicated examiner. Traditionally, hackers have used anti-forensic methods as a means of hiding their tools, techniques, and identities from forensic investigators. However, anti-forensic methodologies can also be adopted for defensive purposes. In particular, Anti-Forensic techniques have the ability to greatly increase the level of effort required to reverse-engineer malicious code. This is especially useful when the attacker has full access to the memory, disk, and possibly even the processor of a computer system running the protection software.

For this effort, Pikewerks has identified a number of anti-forensic research areas that would significantly enhance the confidentiality and integrity of executable code, data, and cryptographic materials through all stages of operation: at rest, in transit, and during execution. These areas include novel out-of-band storage and transmission techniques within Commercial Off The Shelf (COTS) computers, which go beyond the highest level of access available to an attacker and thus dramatically increase the level of effort required to fully

identify, understand, or reverse-engineer the underlying code. The end goal of this development effort is a diverse suite of innovative anti-forensic capabilities that can be easily integrated into, and deployed with, technologies where stealth is critical.

Relevance to DCG Technical Area 1

This effort has resulted in the identification of anti-forensic capabilities that could be employed by sophisticated malware analysis authors, like the kind the Cyber GNOME Project is expected to engage. This effort is particularly useful to the DCG effort as it demonstrates the advanced research and development ongoing within Pikewerks Corporation. For the DCG effort revolutionary methods and techniques must be employed to analyze sophisticated malware that will in the future likely employ many of the techniques being studied by Pikewerks. Utilizing this research will assist in developing methods for identifying, analyzing, and relating sophisticated anti-forensic techniques within malware. The approaches developed include anti-forensic file system storage techniques, indirect function hooking, memory protection techniques using processor debug registers, and BIOS-based anti-forensic strategies. As part of the development of these techniques, Pikewerks has written several kernel modules and custom analysis capabilities for Windows and Linux that both characterize and detect sophisticated anti-forensic techniques.

III.F.1.6 UC Berkeley Past Performance

UC Berkeley is a top institution and Computer Science Dept. at UC Berkeley ranks #1 in the US according to USA News. UC Berkeley routinely receives grants and contracts from various government agencies and has consistently delivered excellent results and performance. Research resulted from government grants and contracts has led to revolutionary technical innovation in many different areas. In particular, the earlier work on BitBlaze was funded by NSF and DoD and has led to great success and improvement in novel binary analysis techniques and tools for computer security.

III.G Place of Performance, Facilities, and Locations

The GDAIS team will perform work at their individual locations. We propose no classified work. Each team member has a primary location and may have secondary locations in which they will perform their research and development. A summary listing is provided in Figure 9 and Figure 10.

Figure 9. Summary of Team Member Locations

Team Member	Location
GDAIS	Centennial, Colorado
HBGary Federal	Sacramento, California
UC Berkeley	Berkeley, California
SRI International	Menlo Park, California
AVI-Secure Decisions	Northport, New York
Pikewerks	Alexandria, Virginia



Figure 10. DARPA Cyber Genome Program Team Locations

III.H Detailed Teaming Structure

Detail support enhancing that of Section II, including formal teaming agreements that are required to execute this program.

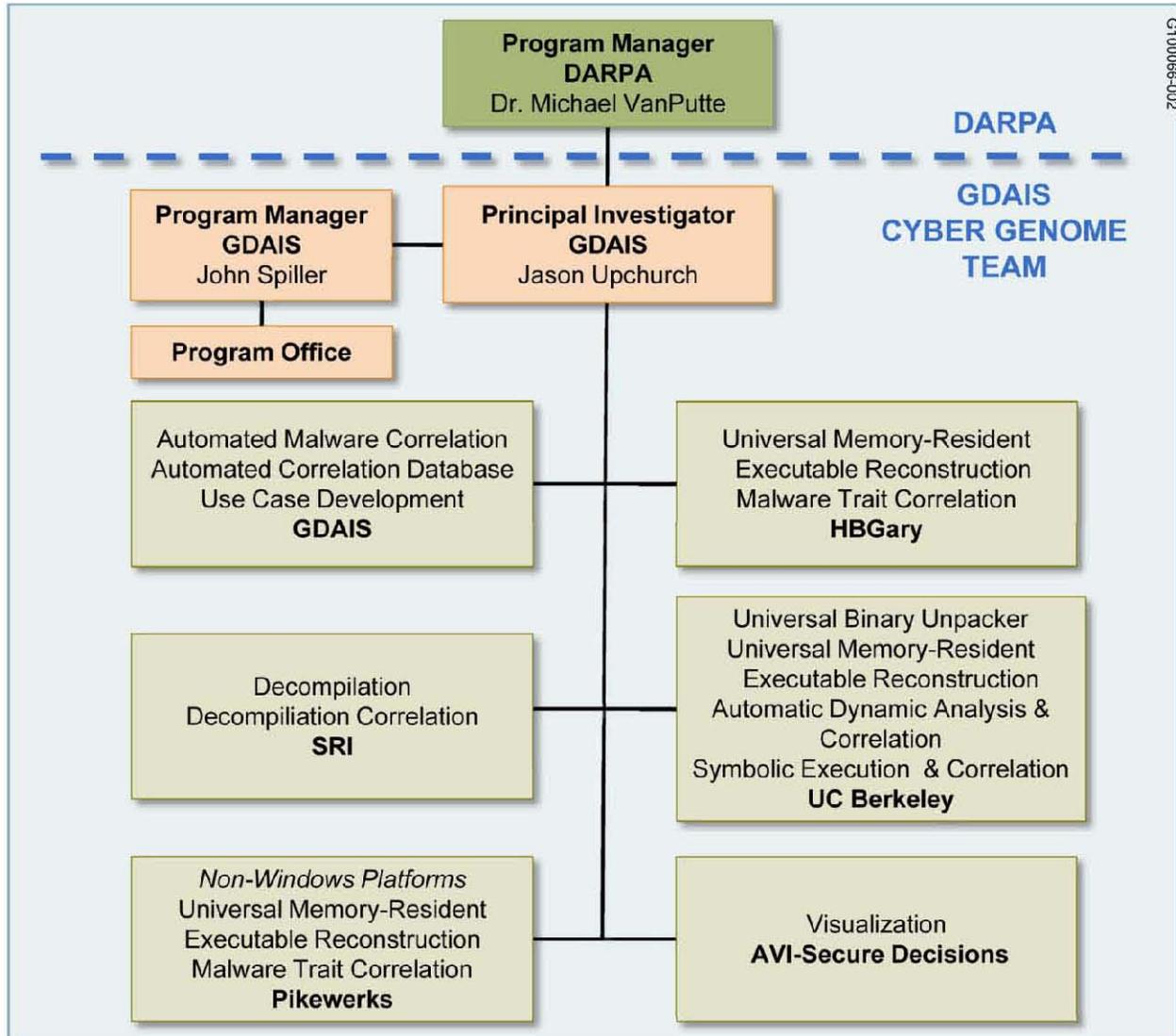


Figure 11. DARPA Cyber Genome Team

III.I Cost Schedules and Milestones

Cost schedules and measurable milestones for the proposed research, including estimates of cost for each task in each year of the effort delineated by the primes and major subcontractors, total cost, and any company cost share.

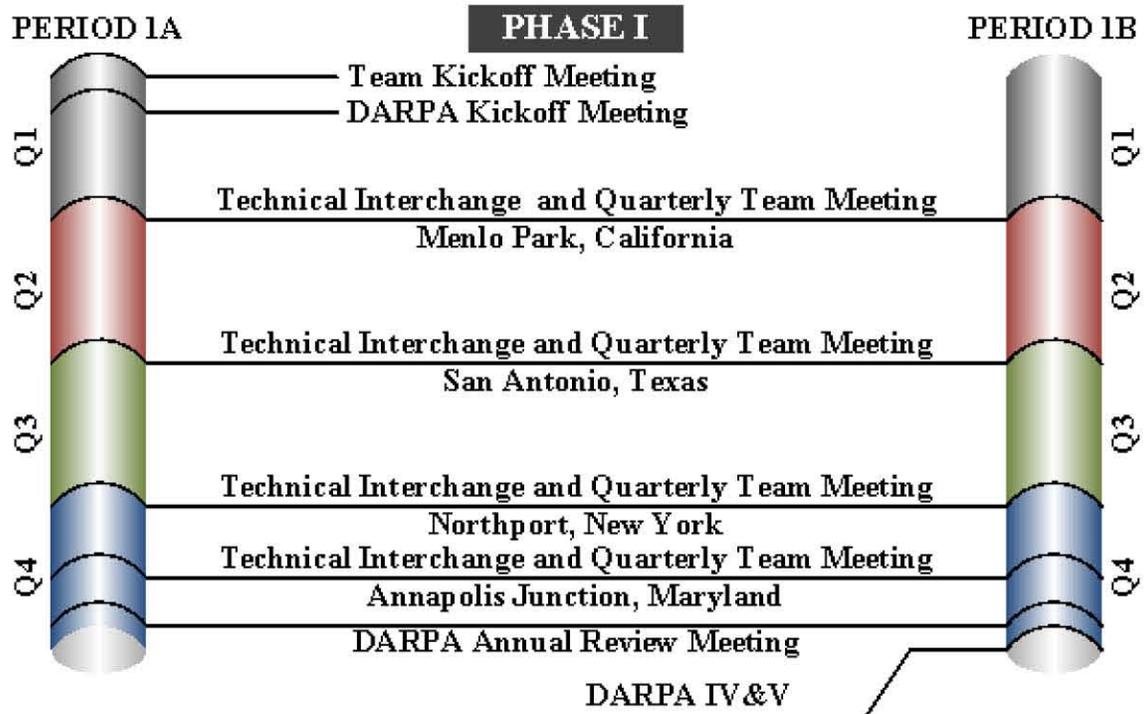


Figure 12. Phase I Schedule

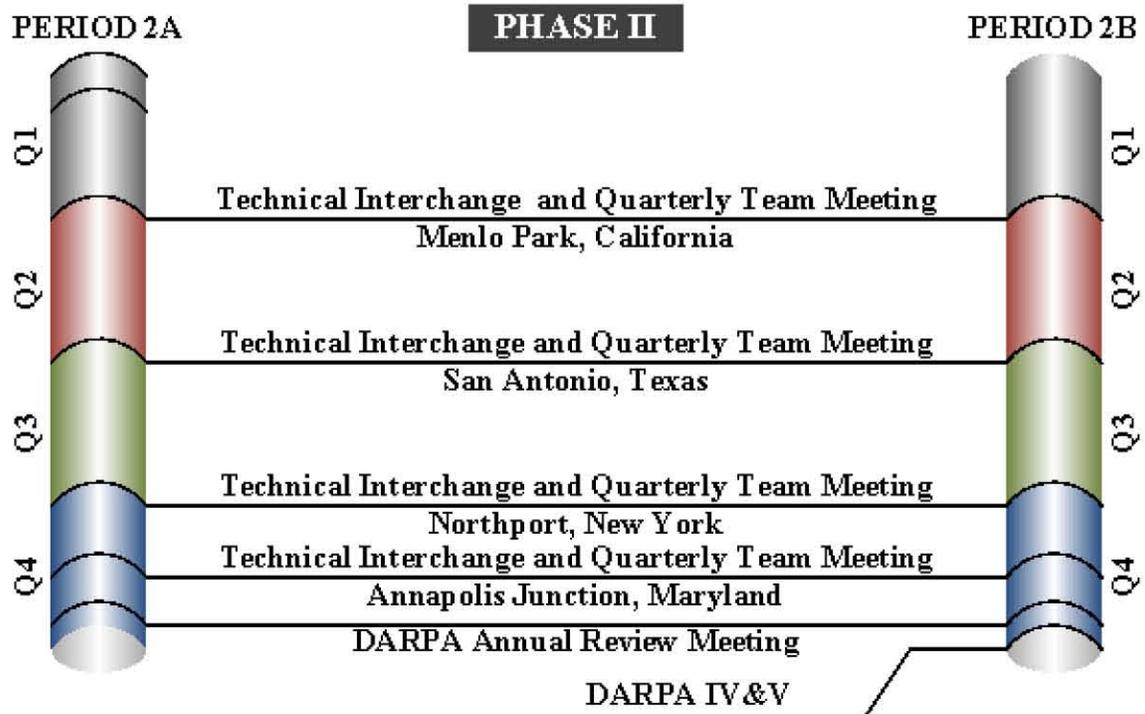


Figure 13. Phase II Schedule

III.J Data, Intellectual Property, and Privacy

All proposals must include a description of the data they will use during their research, potential privacy issues, and how they propose mitigating any privacy issues.

IV. Bibliography of Technical Papers and Research Notes

AVI-Secure Decisions

1. D'Amico, A., Goodall, J., Tesone, D. and Kopylec, J. (2007) "Visual discovery in computer network defense," IEEE Proceedings on Computer Graphics and Applications, Special Issue on Discovering the Unexpected, p. 20 – 27.
2. D'Amico, A., Whitley, K., Tesone, D., O'Brien, B., and Roth, E. (2005) "Achieving cyber defense situational awareness: A cognitive task analysis of information assurance analysts," Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting, p. 229-233.
3. D'Amico, A. & Larkin, M. (2001) "Methods of visualizing temporal patterns in and mission impact of computer security breaches," Proceedings of DARPA Information Survivability Conference and Exposition (DISCEX II), IEEE Computer Society, p. 343-351.

HBGary Federal

4. Ahmed, F., H. Hameed, et al. (2009). Using spatio-temporal information in API calls with machine learning algorithms for malware detection. Proceedings of the 2nd ACM workshop on Security and artificial intelligence. Chicago, Illinois, USA, ACM: 55-62.
5. Anh, M. N. (2009). MAVMM: Lightweight and Purpose Built VMM for Malware Analysis.
6. Bertrand, A. (2009). Runtime Protection via Dataflow Flattening.
7. Carbone, M., W. Cui, et al. (2009). Mapping kernel objects to enable systematic integrity checking. Proceedings of the 16th ACM conference on Computer and communications security. Chicago, Illinois, USA, ACM: 555-565.
8. Chen, H., L. Yuan, et al. (2009). Control flow obfuscation with information flow tracking. Proceedings of the 42nd Annual IEEE/ACM International Symposium on Microarchitecture. New York, New York, ACM: 391-400.
9. Chouchane, M. R., A. Walenstein, et al. (2007). Statistical signatures for fast filtering of instruction-substituting metamorphic malware. Proceedings of the 2007 ACM workshop on Recurring malcode. Alexandria, Virginia, USA, ACM: 31-37.
10. Crandall, J. R., R. Ensafi, et al. (2008). The ecology of Malware. Proceedings of the 2008 workshop on New security paradigms. Lake Tahoe, California, USA, ACM: 99-106.
11. Desmond, L. (2010). RBACS: Rootkit Behavioral Analysis and Classification System.
12. George, S. O. (2009). Using Nature to Best Clarify Computer Security and Threats.
13. Hengli, Z. (2010). Malicious Executables Classification Based on Behavioral Factor Analysis.
14. Hu, X., T.-c. Chiueh, et al. (2009). Large-scale malware indexing using function-call graphs. Proceedings of the 16th ACM conference on Computer and communications security. Chicago, Illinois, USA, ACM: 611-620.

15. Jiang, X., X. Wang, et al. (2007). Stealthy malware detection through vmm-based "out-of-the-box" semantic view reconstruction. Proceedings of the 14th ACM conference on Computer and communications security. Alexandria, Virginia, USA, ACM: 128-138.
16. Kang, M. G., H. Yin, et al. (2009). Emulating emulation-resistant malware. Proceedings of the 1st ACM workshop on Virtual machine security. Chicago, Illinois, USA, ACM: 11-22.
17. Lakhota, A., D. R. Boccoardo, et al. (2010). Context-sensitive analysis of obfuscated x86 executables. Proceedings of the 2010 ACM SIGPLAN workshop on Partial evaluation and program manipulation. Madrid, Spain, ACM: 131-140.
18. Maughan, D. (2010). "The need for a national cybersecurity research and development agenda." Commun. ACM 53(2): 29-31.
19. Min, F. (2009). Detecting virus mutations via dynamic matching.
20. Minoru, F. (2000). A New Rule Generation Method from Neural Networks Formed Using a Genetic Algorithm with Virus Infection.
21. Mohammad, T. (2010). A Survey of Hardware Trojan Taxonomy and Detection. K. Farinaz. 27: 10-25.
22. Norman, S. (2010). Metrics for Mitigating Cybersecurity Threats to Networks. 14: 64-71.
23. Preda, M. D., M. Christodorescu, et al. (2007). A semantics-based approach to malware detection. Proceedings of the 34th annual ACM SIGPLAN-SIGACT symposium on Principles of programming languages. Nice, France, ACM: 377-388.
24. Preda, M. D., M. Christodorescu, et al. (2008). "A semantics-based approach to malware detection." ACM Trans. Program. Lang. Syst. 30(5): 1-54.
25. Sean, F. (2009). Analyzing and Detecting Malicious Flash Advertisements.
26. Shakeel, B. (2009). Protecting Commodity Operating System Kernels from Vulnerable Device Drivers.
27. Tabish, S. M., M. Z. Shafiq, et al. (2009). Malware detection using statistical analysis of byte-level file content. Proceedings of the ACM SIGKDD Workshop on CyberSecurity and Intelligence Informatics. Paris, France, ACM: 23-31.
28. Tengfei, Y. (2009). Anti-debugging Framework Based on Hardware Virtualization Technology.
29. Wei, P. (2009). A Novel Anomaly Detection Approach for Executable Program Security.
30. Wei, W. (2009). A Hierarchical Artificial Immune Model for Virus Detection.
31. Wenjian, Y. (2009). A Control Flow Graph Reconstruction Method from Binaries Based on XML.
32. Xinran, W. (2009). Detecting Software Theft via System Call Based Birthmarks.
33. Xue, J., C. Hu, et al. (2009). Metamorphic malware detection technology based on aggregating emerging patterns. Proceedings of the 2nd International Conference on Interaction Sciences: Information Technology, Culture and Human. Seoul, Korea, ACM:

1293-1296.

34. Yuan-yuan, L. (2009). AOP-Based Attack on Obfuscated Java Code.
35. Zhou, Y. and W. M. Inge (2008). Malware detection using adaptive data compression. Proceedings of the 1st ACM workshop on Workshop on AISEC. Alexandria, Virginia, USA, ACM: 53-60.

SRI International

36. P. Porras, H. Saidi, V. Yegneswaran (2007). "A multi-perspective analysis of the Storm (Peacomm) Worm." SRI Technical Report, November 2007. <http://www.cyber-ta.org/pubs/StormWorm>
37. G. Gu, P.A. Porras, V. Yegneswaran, M. Fong, W. Lee. (2007), "BotHunter: Detecting Malware Infection Through IDS-Driven Dialog Correlation." In Proceedings of the 16th USENIX Security Symposium (Security'07), Boston, MA, August 2007.
38. M. Sharif, V. Yegneswaran, H. Saidi, P.A Porras, W. Lee (2008). "Eureka: A Framework for Enabling Static Malware Analysis." In Proceedings of the 13th European Symposium on Research in Computer Security, Malaga, Spain, October 2008.
39. Phillip Porras, Hassen Saidi, Vinod Yegneswaran (2009). "A Foray into Conficker's Logic and Rendezvous Points" In Proceedings of 2nd USENIX Workshop on Large-Scale Exploits and Emergent Threats (LEET).
40. Phillip Porras, Hassen Saidi, Vinod Yegneswaran (2009). "Conficker C Analysis." SRI Technical Report, April 2009 <http://mtc.sri.com/Conficker/addendumC/index.html>
41. Zhaosheng Zhu, Vinod Yegneswaran, Yan Chen (2009). "Using Failure Information Analysis to Detect Enterprise Zombies." In the Proc. of the 5th International Conference on Security and Privacy in Communication Networks (SecureComm).
42. Phillip Porras, Hassen Saidi, Vinod Yegneswaran (2009). "Conficker C P2P Protocol and Implementation" SRI Technical Report. <http://mtc.sri.com/Conficker/P2P/index.html>
43. P. Porras, H. Saidi, V. Yegneswaran (2009). "An analysis of the Ikee.B (Duh) Iphone botnet." SRI Technical Report, December 2009 <http://www.cyber-ta.org/pubs/StormWorm>
44. Guofei Gu, Vinod Yegneswaran, Phillip Porras, Jennifer Stoll, Wenke Lee (2009). "Active Botnet Probing to Identify Obscure Command and Control Channels." In Proceedings of 2009 Annual Computer Security Applications Conference (ACSAC'09), Honolulu, Hawaii, December 2009.

UC Berkeley

45. James Newsome and Dawn Song (2005). "Dynamic Taint Analysis: Automatic Detection, Analysis, and Signature Generation of Exploit Attacks on Commodity Software." In Proceedings of the Network and Distributed Systems Security Symposium, February 2005.
46. David Brumley, James Newsome, Dawn Song, Hao Wang, and Somesh Jha (2006). "Towards Automatic Generation of Vulnerability Signatures." In Proceedings of the IEEE Symposium on Security and Privacy, May 2006.

47. James Newsome, David Brumley, Jason Franklin, and Dawn Song (2006). "Replayer: Automatic Protocol Replay by Binary Analysis." In Proceedings of the 13th ACM Conference on Computer and Communications Security (CCS), October 2006.
48. David Brumley, Juan Caballero, Zhenkai Liang, James Newsome, and Dawn Song (2007). "Towards Automatic Discovery of Deviations in Binary Implementations with Applications to Error Detection and Fingerprint Generation." In Proceedings of USENIX Security Symposium, Aug 2007.
49. Min Gyung Kang, Pongsin Poosankam, and Heng Yin (2007). "Renovo: A Hidden Code Extractor for Packed Executables." In Proceedings of the 5th ACM Workshop on Recurring Malcode (WORM), Oct 2007.
50. Heng Yin, Dawn Song, Manuel Egele, Christopher Kruegel, and Engin Kirda (2007). "Panorama: Capturing System-wide Information Flow for Malware Detection and Analysis." In Proceedings of ACM Conference on Computer and Communication Security, Oct 2007.
51. Juan Caballero, Heng Yin, Zhenkai Liang, and Dawn Song (2007). "Polyglot: Automatic Extraction of Protocol Message Format using Dynamic Binary Analysis." In Proceedings of the 14th ACM Conference on Computer and Communications Security (CCS), October 2007.
52. Heng Yin, Zhenkai Liang, and Dawn Song (2008). "HookFinder: Identifying and Understanding Malware Hooking Behaviors." In Proceedings of the 15th Annual Network and Distributed System Security Symposium, February 2008.
53. David Brumley, Pongsin Poosankam, Dawn Song, and Jiang Zheng (2008). "Automatic Patch-Based Exploit Generation is Possible: Techniques and Implications" In Proceedings of the IEEE Symposium on Security and Privacy, May 2008.
54. James Newsome, Stephen McCamant, and Dawn Song (2009). "Measuring Channel Capacity to Distinguish Undue Influence" In Proceedings of the Fourth ACM SIGPLAN Workshop on Programming Languages and Analysis for Security, June 2009.
55. Prateek Saxena, Pongsin Poosankam, Stephen McCamant, and Dawn Song (2009). "Loop-Extended Symbolic Execution on Binary Programs" In Proceedings of the ACM/SIGSOFT International Symposium on Software Testing and Analysis, July 2009.
56. Juan Caballero, Pongsin Poosankam, Christian Kreibich, and Dawn Song (2009). "Dispatcher: Enabling Active Botnet Infiltration using Automatic Protocol Reverse-Engineering" In Proceedings of the 16th ACM Conference on Computer and Communication Security, November 2009.
57. Juan Caballero, Noah M. Johnson, Stephen McCamant, and Dawn Song (2010). "Binary Code Extraction and Interface Identification for Security Applications" In Proceedings of the 17th Annual Network and Distributed System Security Symposium, February 2010.