The Need to Support of Data Flow Graph Visualization of Forensic Lucid Programs, Forensic Evidence, and their Evaluation by GIPSY

Serguei A. Mokhov
Concordia University
Montreal, QC, Canada
mokhov@cse.concordia.ca

Joey Paquet
Concordia University
Montreal, QC, Canada
paquet@cse.concordia.ca

Mourad Debbabi
Concordia University
Montreal, QC, Canada
debbabi@ciise.concordia.ca

Abstract

Lucid programs are data-flow programs and can be visually represented as data flow graphs (DFGs) and composed visually. Forensic Lucid, a Lucid dialect, is a language to specify and reason about cyberforensic cases. It includes the encoding of the evidence (representing the context of evaluation) and the crime scene modeling in order to validate claims against the model and perform event reconstruction, potentially within large swaths of digital evidence. To aid investigators to model the scene and evaluate it, instead of typing a Forensic Lucid program, we propose to expand the design and implementation of the Lucid DFG programming onto Forensic Lucid case modeling and specification to enhance the usability of the language and the system and its behavior. We briefly discuss the related work on visual programming and DFG modeling in an attempt to define and select one approach or a composition of approaches for Forensic Lucid based on various criteria such as previous implementation, wide use, formal backing in terms of semantics and translation. In the end, we solicit the readers’ constructive, opinions, feedback, comments, and recommendations within the context of this short discussion.

Keywords: Forensic Lucid, DFG, GIPSY, forensic computing

1 Overview

Cyberforensic analysis has to do with automated or semi-automated processing of, and reasoning about, digital evidence, witness accounts, and other details from cybercrime incidents (involving computers, but not limited to them). Analysis is one of the phases in cybercrime investigation (while the other phases focus on evidence collection, preservation, chain of custody, information extraction that precede the analysis). The phases that follow the analysis are formulation of a report and potential prosecution, typically involving expert witnesses. There are quite a few techniques, tools (hardware and software), and methodologies have been developed for the mentioned phases of the process. A lot of attention has been paid to the tool development for evidence collection and preservation; a few tools have been developed to aid data “browsing” on the confiscated storage media, log files, memory, and so on. A lot less number of tools have been developed for case analysis of the data (e.g. Sleuthkit), and the existing commercial packages (e.g. Encase or FTK) are very expensive. Even less so there are case management, event modeling, and event reconstruction, especially with a solid formal theoretical base. The first formal approach to the cybercrime investigation was the finite-state automata (FSA) approach by Gladyshev et. al. Their approach, however, is unduly complex to use and to understand for non-theoretical-computer science or equivalent minded investigators.
The aim of Forensic Lucid is to alleviate those difficulties, be sound and complete, expressive and usable, and provide even further usability improvements with the GUI to do data-flow graph-based (DFG) programming that allows translation between DFGs and the Forensic Lucid code for compilation and evaluation. In a previous related work a similar solution for Indexical Lucid was implemented in the General Intensional Programming System (GIPSY) already [5], but requires additional forensic and imperative extensions.

The goal of Forensic Lucid in the cyberforensic analysis is to be able to express in a program form the encoding of the evidence, witness stories, and evidential statements, that can be tested against claims to see if there is a possible sequence or multiple sequences of events that explain a given story. As with the Gladyshev’s FSA, it is designed to aid investigators to avoid ad-hoc conclusions and have them look at the possible explanations the Forensic Lucid program “execution” would yield and refine the investigation, as was shown in the works by Gladyshev et al. [9, 8] where hypothetical investigators failed to analyze all the “stories” and their plausibility before drawing conclusions.

In Figure 1 [22] is a general design overview of the Forensic Lucid compilation and evaluation process involving various components and systems. Of main interest to this work are the inputs to the compiler – the Forensic Lucid fragments (hierarchical context representing the evidence and witness accounts) and programs (descriptions of the crime scenes as transition functions) can come from different sources, including the visual interactive DFG editor that would be used by the investigators at the top-right corner of the image. Once the complete evidential knowledge of the case and the crime scene model are composed, the whole specification is compiled by the compiler depicted as GIPC on the image (General Intensional Program Compiler). The compiler produces an intermediate version of the compiled program as an AST and a contextual dictionary of all identifiers among other things, that evaluation engines (under the GEE component) understand. The proposed Forensic Lucid engines are designed to use the traditional eduction, AspectJ-based tracing, and probabilistic model checking with PRISM.

2 Related Work

There are a number of items and proposals in graph-based visualization and the corresponding languages.

In GIPSY, our own work in the area includes the theoretical foundation and initial practical implementation of the DFGs [25, 5]. First, Faustini proved that any Indexical Lucid program can be represented as a DFG [7]; Paquet subsequently expanded on this for multidimensional intensional programs as e.g. shown in Figure 2 [25]. Ding further materialized to a good extent Paquet’s notion within the GIPSY projects in [5] in 2004 using [3]’s lefty’s GUI and dot languages [2] along with bi-directional translation between GIPL’s or Indexical Lucid’s abstract syntax trees (ASTs) to dot’s and back.

Additionally, a part of the proposed related work on visualization and control of communication patterns and load balancing idea was to have a “3D editor” within RIPE’s DemandMonitor that will render in 3D space the current communication patterns of a GIPSY program in execution or replay it back and allow the user visually to redistribute demands if they go off balance between workers. A kind of virtual 3D remote control with a mini expert system, an input from which can be used to teach the planning, caching, and load-balancing algorithms to perform efficiently next time a similar GIPSY application is run as was proposed in [15]. Related work by several researchers on visualization of load balancing, configuration, formal systems for diagrammatic modeling and visual languages and the corresponding graph systems are presented.
Figure 1: Forensic Lucid Compilation and Evaluation Flow in GIPSY
They all define some key concepts that are relevant to our visualization mechanisms within GIPSY and its corresponding General Manager Tier (GMT) [12].

We propose to build upon those works to represent the nested evidence, crime scene as a 2D or even 3D DFG, and the reconstructed events flow upon evaluation. Such a feature is projected in the near future to support the previous work on intensional forensic computing, evidence modeling and encoding, and Forensic Lucid [18, 19, 20, 21] and MARFL [17, 16] (where the intensional hybrid programming languages are being realized within the GIPSY platform to investigate the languages’ properties and test the run-time aspects thereof) in order to aid investigator’s tasks to build and evaluate digital forensic cases.

Examples

For that related work an conceptual example of a 2D DFG corresponding to a simple Lucid program is in Figure 2. The actual current rendering of such graphs is exemplified in Figure 3 from Ding [5] in the GIPSY environment.

In Figure 7 is the conceptual hierarchical nesting of the evidential statement es context elements, such as observation sequences os, their individual observations o (consisting of the properties being observed \((P, \text{min, max, w, t})\), details of which are discussed in the referenced related works). These 2D conceptual visualizations are proposed to be renderable at least in 2D or in 3D via an interactive interface to allow modeling complex crime scenes and multidimensional evidence on demand. The end result could look like something expanding or “cutting out” nodes or complex-type results conceptually exemplified in Figure 4.

![Figure 2: Canonical Example of a 2D Data Flow Graph-Based Program](image-url)
Figure 3: Example of an Actual Rendered 2D Data Flow Graph-Based Program with Graphviz

Figure 4: Modified Example of a 2D Data Flow Graph-based Program with 3D Elements. Cutout image credit is that of Europa found on Wikipedia [external link]: http://en.wikipedia.org/wiki/File:PIA01130_Interior_of_Europa.jpg from NASA
Figure 5: Conceptual Example of a 3D Observation Node. Cutout image credit is that of Europa found on Wikipedia [http://en.wikipedia.org/wiki/File:PIA01130_Interior_of_Europa.jpg](http://en.wikipedia.org/wiki/File:PIA01130_Interior_of_Europa.jpg) from NASA.

Figure 6: Example of a BPEL Graph with Asynchronous Flows [24]
3 Visualization of Forensic Lucid

3.1 3 Dimensions?

The need to represent visually forensic cases, evidence, and other specification components is obvious for usability and other issues. Placing it in 3D helps to structure the “program” (specification) and the case in 3D space can help arrange and structure the case in a virtual environment better with the evidence items encapsulated in 3D balls like Russian dolls, and can be navigated in depth to any level of detail via clicking (cf. Figure 5).

The depth and complexity of operational semantics and demand-driven (eductive) execution model are better represented and comprehended visually in 3D especially when doing event reconstruction. Ding’s implementation allows navigation from a graph to a graph by expanding more complex nodes to their definitions, e.g. more elaborate operators such whenever (wvr) or advances upon (upon).

3.2 Requirements Summary

Some immediate requirements to realize the envisioned DFG visualization of Forensic Lucid programs and their evaluation:

- Visualization of the hierarchical evidential statements (potentially deeply nested context), cf. Figure 7.
- Placement of hybrid intensional-imperative nodes into the DFGs such as mixing Java and Lucid program fragments. The GIPSY research and development group’s previous works did not deal with the way on how to augment the DFGAnalyzer and DFGGenerator of Ding to support hybrid GIPSY programs. This can be addressed by adding an unexpandable imperative DFG node to the graph. To make it more useful, i.e. expandable and so it’s possible to generate the GIPSY code off it or reverse it back. The newer versions of Graphviz also have new support features that are more usable for our needs at the present. Additionally, with the advent of JOOIP [29] the Java 5 ASTs are available made available along with embedded Lucid fragments that can be tapped into when generating the dot code’s AST.
- Java-based wrapper for the DFG Editor of Yimin Ding [5] to enable its native use within Java-based GIPSY and plug-in IDE environments like Eclipse.
3.3 Selection of the Language and Tools

One of the goals of this work is to find the optimal technique, with soundness and completeness and formal specifications ease of implementation and usability; thus we’d like to solicit opinions and insights of this work in selecting the technique or a combination of techniques, which seems a more plausible outcome.

The current design allows any of the implementation to be chosen or a combination of them.

Graphviz

First, the most obvious is Ding’s [5] basic DFG implementation within GIPSY as it is already part of the project and done for the two predecessor Lucid dialects. Additionally, the modern version of Graphviz now also has integration with Eclipse [6], so GIPSY’s IDE – RIPE (Run-time Interactive Programming Environment) – may very well be the an Eclipse-based plug-in.

PureData

Puckette came up with the PureData [26] language and its commercial offshoots, which also employ DFG-like programming with boxes and inlets and outlets of any data types graphically collected and allowing sub-graphs and external implementations of inlets in procedural languages. Puckette’s original design was targeting signal processing for electronic music and video processing and production for interactive artistic and performative processes but has since outgrown that notion. The PureData externals allow deeper media visualizations in OpenGL, video, etc. thereby potentially enhancing the whole aspect of the process significantly.

BPEL

The BPEL (Business Process Execution Language) and its visual realization within NetBeans [27, 28] for SOA (service-oriented architectures) and web services is another good model for inspiration [13, 10] that has recently undergone a lot of research and development, including flows, picking structures, and faults, parallel/ asynchronous and sequential activities. More importantly, BPEL notations have a backing formalism modeled upon based on Petri nets (see e.g. visual BPEL graph in BPEL Designer (first came with the NetBeans IDE) in Figure 6 that illustrates two flows and 3 parallel activities in each flow as well asynchrony and timeouts modeling. This specification actually translates to an executable Java web services code).

4 Conclusion

With the goal to have a visual DFG-based tool to model Forensic Lucid case specification we deliberate on the possible choice of the languages and paradigms within today’s technologies and their practicality and attempt to build upon previous sound work in this area. Main choices so far identified include Ding-derived Graphviz-based implementation, PureData-based, or BPEL-like. All languages are more or less industry standards and have some formal backings; the ones that don’t may require additional work on to formally specify their semantics and prove correctness and sounds of translation to and from Forensic Lucid.

The main problem with PureData and Graphviz’s dot is that their languages do not have formal semantics specified only some semantic notes and lexical and grammatical structures (e.g. see dot’s [2]). If we use any and all of these, we will have to provide translation rules and their semantics and equivalence to the original Forensic Lucid specification similarly as it
is e.g. was done by Jarraya for the UML 2.0/SysML state/activity diagrams and probabilities in [11] when translating to PRISM or equivalently for Forensic Lucid to PRISM translation to do model-checking.

Thus, this work at this stage is to solicit comments and recommendations on the proposed choices for the task. Given the author’s some familiarity with all three languages, the final choice may result being an intermediate form or a collection of forms mutually translatable.

Acknowledgments

This work was supported in part by NSERC and the Faculty of Engineering and Computer Science, Concordia University, Montreal, Canada.

References

[1] Gerard Allwein and Jon Barwise, editors. *Logical reasoning with diagrams*. Oxford University Press, Inc., New York, NY, USA, 1996.

[2] AT&T Labs Research and Various Contributors. The DOT language. [online], 1996–2011. http://www.graphviz.org/pub/scm/graphviz2/doc/info/lang.html

[3] AT&T Labs Research and Various Contributors. Graphviz – graph visualization software. [online], 1996–2011. http://www.graphviz.org/

[4] R. Bardohl, M. Minas, G. Taentzer, and A. Schühr. Application of graph transformation to visual languages. In *Handbook of Graph Grammars and Computing by Graph Transformation: Applications, Languages, and Tools*, volume 2, pages 105–180. World Scientific Publishing Co., Inc., River Edge, NJ, USA, 1999.

[5] Yimin Ding. Automated translation between graphical and textual representations of intensional programs in the GIPSY. Master’s thesis, Department of Computer Science and Software Engineering, Concordia University, Montreal, Canada, June 2004. http://newton.cs.concordia.ca/~paquet/filetransfer/publications/theses/DingYiminMSc2004.pdf

[6] Eclipse contributors et al. Eclipse Platform. eclipse.org, 2000–2011. http://www.eclipse.org last viewed February 2010.

[7] Anthony A. Faustini. *The Equivalence of a Denotational and an Operational Semantics of Pure Dataflow*. PhD thesis, University of Warwick, Computer Science Department, Coventry, United Kingdom, 1982.

[8] Pavel Gladyshev. Finite state machine analysis of a blackmail investigation. *International Journal of Digital Evidence*, 4(1), 2005.

[9] Pavel Gladyshev and Ahmed Patel. Finite state machine approach to digital event reconstruction. *Digital Investigation Journal*, 2(1), 2004.

[10] IBM, BEA Systems, Microsoft, SAP AG, and Siebel Systems. Business Process Execution Language for Web Services version 1.1. [online], IBM, February 2007. http://www.ibm.com/developerworks/library/specification/ws-bpel/

[11] Yosr Jarraya. *Verification and Validation of UML and SysML Based Systems Engineering Design Models*. PhD thesis, Department of Electrical and Computer Engineering, Concordia University, Montreal, Canada, February 2010.

[12] Yi Ji. Scalability evaluation of the GIPSY runtime system. Master’s thesis, Department of Computer Science and Software Engineering, Concordia University, Montreal, Canada, March 2011.

[13] Dieter Koenig. Web services business process execution language (WS-BPEL 2.0): The standards landscape. Presentation, IBM Software Group, 2007.

[14] N. G. Miller. *A Diagrammatic Formal System for Euclidean Geometry*. PhD thesis, Cornell University, U.S.A, 2001.
[15] Serguei A. Mokhov. Towards hybrid intensional programming with JLucid, Objective Lucid, and General Imperative Compiler Framework in the GIPSY. Master's thesis, Department of Computer Science and Software Engineering, Concordia University, Montreal, Canada, October 2005. ISBN 0494102934; online at http://arxiv.org/abs/0907.2640.

[16] Serguei A. Mokhov. Encoding forensic multimedia evidence from MARF applications as Forensic Lucid expressions. In Tarek Sobh, Khaled Elleithy, and Ausif Mahmood, editors, Novel Algorithms and Techniques in Telecommunications and Networking, proceedings of CISSE’08, pages 413–416, University of Bridgeport, CT, USA, December 2008. Springer. Printed in January 2010.

[17] Serguei A. Mokhov. Towards syntax and semantics of hierarchical contexts in multimedia processing applications using MARFL. In Proceedings of the 32nd Annual IEEE International Computer Software and Applications Conference (COMPSAC), pages 1288–1294, Turku, Finland, July 2008. IEEE Computer Society.

[18] Serguei A. Mokhov, Joey Paquet, and Mourad Debbabi. Formally specifying operational semantics and language constructs of Forensic Lucid. In Oliver Göbel, Sandra Frings, Detlef Günther, Jens Neden, and Dirk Schadt, editors, Proceedings of the IT Incident Management and IT Forensics (IMF’08), LNI140, pages 197–216. GI, September 2008.

[19] Serguei A. Mokhov, Joey Paquet, and Mourad Debbabi. Towards automated deduction in blackmail case analysis with Forensic Lucid. In Joseph S. Gauthier, editor, Proceedings of the Huntsville Simulation Conference (HSC’09), pages 326–333. SCS, October 2009. Online at http://arxiv.org/abs/0906.0049.

[20] Serguei A. Mokhov, Joey Paquet, and Mourad Debbabi. Towards automatic deduction and event reconstruction using Forensic Lucid and probabilities to encode the IDS evidence. In S. Jha, R. Sommer, and C. Kreibich, editors, Proceedings of RAID’10, LNCS 6307, pages 508–509. Springer, September 2010.

[21] Serguei A. Mokhov and Emil Vassev. Self-forensics through case studies of small to medium software systems. In Proceedings of IMF’09, pages 128–141. IEEE Computer Society, September 2009.

[22] Serguei A. Mokhov, Emil Vassev, Joey Paquet, and Mourad Debbabi. Towards a self-forensics property in the ASSL toolset. In Proceedings of C3S2E’10, pages 108–113. ACM, May 2010.

[23] NetBeans Community. NetBeans Integrated Development Environment. [online], 2004–2011. http://www.netbeans.org.

[24] OpenESB Contributors. BPEL service engine. [online], 2009. https://open-esb.dev.java.net/BPELSE.html.

[25] Joey Paquet. Scientific Intensional Programming. PhD thesis, Department of Computer Science, Laval University, Sainte-Foy, Canada, 1999.

[26] Miller Puckette and PD Community. Pure Data. [online], 2007–2011. http://puredata.org.

[27] Sun Microsystems, Inc. NetBeans 6.7.1. [online], 2009–2010. http://netbeans.org/downloads/6.7.1/index.html.

[28] Phan C. Vinh and Jonathan P. Bowen. On the visual representation of configuration in reconfigurable computing. Electron. Notes Theor. Comput. Sci., 109:3–15, 2004.

[29] Ai Hua Wu. OO-IP Hybrid Language Design and a Framework Approach to the GIPC. PhD thesis, Department of Computer Science and Software Engineering, Concordia University, Montreal, Canada, 2009.

[30] Chunfang Zheng and J. Robert Heath. Simulation and visualization of resource allocation, control, and load balancing procedures for a multiprocessor architecture. In MS’06: Proceedings of the 17th IASTED international conference on Modelling and simulation, pages 382–387, Anaheim, CA, USA, 2006. ACTA Press.
Index

API
  DemandMonitor, 2
  DFGAnalyzer, 7
  DFGGenerator, 7
  upon, 7
  wvr, 7
  AspectJ, 2

DFG, 2 4 7 8

Forensic Lucid, 1 4 7 9
Frameworks
  GEE, 2
  GIPC, 2
  RIPE, 2 8

GEE, 2
GIPC, 2
GIPSY, 1 4 7 8
Graphviz, 7 8

Indexical Lucid, 2

Java, 7
JOOIP, 7

Lucid, 1 7

MARFL, 4

PureData, 8

RIPE, 2 8

Tools
  dot, 2 7 8
  Graphviz, 7 8
  lefty, 2
  PureData, 8