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# AN INTEGRATED DATAFLOW BASED MODEL FOR DIGITAL INVESTIGATION

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## Abstract

This study developed a highly adaptive digital forensic model, applicable to various situations, which clearly describes the digital forensic process and their purposes as well as ensuring the exactness and effectiveness of digital forensic results. It examined the viewpoint of the digital evidence process flow throughout an entire forensic process, and it hoped to provide a complete explanation of the digital forensic procedure and the details of execution. In addition, it proposed three new forensic concepts: primary, supported and comprehensive forensic procedures. The structural hierarchy constructed in the model can be expanded, then divided into its simplest forms, allowing independent task assignments. It further proposed several innovative digital forensic concepts, such as a new feedback mechanism. Finally, this model could provide a detailed list of the resources necessary for an entire forensic activity, applicable to management planning. This model provided a practical description approach and established a comprehensive and uniform digital expression form. The aim is to accumulate and to share experience and knowledge, hoping to create more mature and practical digital forensic science and to provide a reference for the practitioners of digital forensics.

**Keywords:** digital forensic model, digital forensic procedure, forensic data, data flow, digital forensic process, systematic decomposing

## Introduction

In the past forensic process of investigating human crimes, criminals would often leave behind original evidences; these traditional forensic procedures have matured through years of scientific examination and verification procedures [8]. The lack of uniqueness makes digital crimes and their evidences easy to duplicate and alter, which renders traditional forensic procedures and experiences unable to meet the contemporary demands of digital forensics [8]. For these reasons, there is an urgent global demand for advances in digital forensic technologies. Since 2000, researchers have continuously emphasized the significance and applicability of the digital forensic procedure from the field of digital forensic science.

In order to speed scientific research in digital forensics, researchers endeavor to find a universal common forensic procedure in the near future. According to Reith and Carr, the procedures followed by forensic practitioners during the collection, examination, and forensic process have not been standardized with regard to cases of digital crimes [20]. Moreover, Pollitt pointed out that, instead of publication, most digital forensic researches and experiences are either published on the Internet, or communicated in organizational seminars; therefore, these procedures and experiences are not fully accumulated and discussed. The above mentioned conditions account for the current non-standardization of the digital forensic procedure [17].

This study applied the viewpoint of the digital evidence flow throughout an entire forensic process and proposed an integrated digital forensic model. Previous digital forensic studies focused only on the digital forensic procedure or partial concepts of forensics rather than on an integrated digital forensic model, which could comprehensively describe the details and steps of execution in the forensic process and avoid that do not know how to conduct follow-up. Such a complete model has never been published in past literature. This systematic model is able to meet the above mentioned demands as well as resolving the previous model's shortcomings of excessive conceptualization and lack of detailed execution procedures.

Furthermore, there are many other contributions in this study. It proposed three new forensic concepts: primary, supported and comprehensive forensic procedures. It proposed a creative and important feedback mechanism different from previous research, which can provide many details on the execution of said feedback to satisfy various situations. In this study, through uniform explanations of proven processes, these characteristics allow a widespread expression of collated experiences and knowledge, thus establishing a practical sharing method in knowledge management for standardized procedure groups. It also proposed a digital forensic construction dictionary, which defines requirements for personnel, technology, location, and the resources necessary to

complete a complex group of digital forensic processes, allowing practical, accurate budgetary estimations in financial management.

The research of digital forensic models is given in Section 2. Section 3 describes the proposed model and Section 4 discusses the impact of the model. Lastly, Section 5 presents the conclusions.

### Digital Forensics

Digital forensics is commonly defined as the preservation, collection, identification, analysis, recording, and presentation of digital evidence through scientific acquisition and scientific verification methods, with the purpose of reconstruction of discovered cases of crime [8]. Hence, a comprehensive digital forensic processing framework, which can meet the above mentioned requirements, and be operated independently from any specific technology and environment, needs to be developed [20]. Within such a framework forensic practitioners of different organizations could discuss and share their forensic methods and experiences, and digital evidence forensic results could better comply with the principles of impartiality, integrity, and correctness.

#### Procedure-based digital forensic model

Present literature on digital forensic models shows that some studies are concentrated on “forensic procedure” models [1] [2] [3] [4] [5] [6] [7] [8] [11] [12] [15] [18] [20] [22] [24]. These studies focus on describing the guidelines and concepts of various procedures without detailing how these procedures are implemented and developed from different executive levels and perspectives. In addition, some studies have emphasized the concepts of digital forensic implementation [3] [4] [14] [16] [19] [23] [25], namely, exploring and discussing some details of digital forensic concepts and guidelines, rather than how to implement the digital forensic model. Some studies have proposed the concepts of dividing digital forensics into different hierarchies [2] [3] [8] [16] [25], but only addressed conceptualized viewpoints without proposing substantial practices. To summarize, there is a lack of a comprehensive digital forensic model that can completely describe the details of the digital forensic process and decompose the execution steps, while detailing the personnel, technology, locations, and resources required for the digital forensic process.

After reviewing the 16 most commonly seen digital forensic models of digital forensic research, this study selected commonly used procedures of the digital forensic procedure from each piece of research, as shown in Table 1.

#### Digital forensic process and implementation

Although the digital forensic procedure is important,

erroneous or imprecise digital forensic implementation processes and methods may occur due to lack of a thorough understanding of the subsequent details of implementation, even though good digital forensic procedural steps are available. DFRWS defined the digital forensic procedure, and briefly described the scope of these procedures [8]. Although some implementation techniques were mentioned, the study still lacked detailed explanations of the steps of execution.

Previous studies focused on certain aspects, or viewpoints, without systematic and complete description of the digital forensic model. Such a situation means that practitioners are only aware of the concepts, resulting in flawed implementation details and steps, which lead to insufficient evidential power of the forensic results. For example, the “collection” procedure is mentioned by many digital forensic procedure models, but due to the unique characteristics of digital evidence (such as alterability, dissolvability, and duplicability), the question remains of how to show and validate the collected evidences. Thus, more details of the execution steps of the collection procedure should be shown, in order to guarantee the originality and undeniability of the evidence collected.

#### Digital Forensic Model of Dataflow Base

A key point of digital forensics is the necessity, and correctness, of the evidence data process flow, but not the invariable processing procedures. The evidence data process flow begins with the collection of digital evidence data, and then each subsequent step, or processing procedure, is precisely linked to the previous step.

Gane and Sarson proposed using a “Data Flow Diagram” (DFD) for presenting the computer system data processing flow [9]. Likewise, the digital forensic process could also be presented, and described, using the DFD. Since the DFD has well-known semantic expression modes in the field of computer software development, it is conducive to promoting and understanding the digital forensics from an evidence dataflow perspective.

Séamus proposed this new viewpoint of the cybercrime investigation model based on information flow [8]. Basically, in DFD, either term - information flow or data flow - may be exchanged as they have similar meanings. This study will still use the term “data flow” for two reasons. First, this study describes and develops the digital forensic process by applying DFD expressions, and the term of data flow has become a customary and well-known term in the field of computer software development. Second, because what digital forensic processing needs to deal with is forensic data, it is possibly more proper to use data flow when describing digital forensic details at the bottom level.

### Digital Forensic Dataflow Model

This study incorporated the DFD with some adjustment to fit the expression of the digital

forensic model, in order to propose a dataflow-based integrated digital forensic model, as shown in Figure 1. This model is based on the evidence data process

Table 1 The common digital forensic procedure in present research

Source: This study

Writer	Year	Pre-paration	Incident response	Recording	Collection	Exami-nation	Analysis	Presen-tation	Preser-vation
Pollitt	1995		√		√		√	√	
Lee	2001		√		√	√		√	√
DFRWS	2001		√		√	√	√	√	√
Chris	2001	√	√	√		√	√	√	
NCJRS	2001	√		√	√	√	√	√	√
Reith	2002	√	√		√	√	√	√	√
Casey	2003		√	√	√	√			√
Carrier	2003	√	√	√	√		√	√	√
Stephenson	2003				√	√	√	√	
Mocas	2003		√			√		√	
Baryamueeba	2004	√	√	√		√	√		√
Beebe	2004	√	√		√		√	√	√
Carrier	2004	√	√	√	√			√	√
Séamus	2004	√	√	√	√	√	√	√	√
Erbacher	2006			√	√		√	√	
Kent	2006		√	√	√	√	√	√	

flow, with an execution scope able to cover time-flow procedures as well as describing the relationship or processing in detail between mediate evidence in each procedure and execution steps. This model can be expanded to clearly and specifically describe when, how, where, and by whom the digital forensic is implemented, and what evidence was discovered, through which tools and methods.

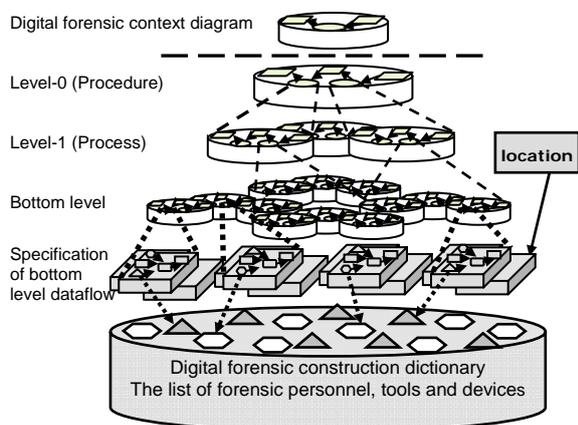


Figure 1 Dataflow-based integrated digital forensic model

Source: This study

In Figure 1, the evidence data, or mediate evidence, is represented by a parallelogram; the procedure (or whole process) is represented by an elliptical symbol; the flow direction of evidence data is represented by an arrow; the development, or expansion, of each procedural phase is represented by a column. The

digital forensic context diagram at the top of the figure is used to present the concept of the purpose of digital forensics, namely, applying forensic procedures throughout an entire process group, to collate the collection of digital evidence, which constructs a forensic evidence report.

Level-0 data flow is used to present the fully developed, or expanded, procedures necessary for the execution of an entire digital forensic activity, and explains which procedure needs to be executed, at which stage.

Level-N data flow is used to develop, and describe, which detailed steps should be taken for any given forensic procedure. This level-diagram is often used to provide more detailed task steps to the practitioners responsible for executing a forensic procedure.

Bottom-level data flow is used to further develop, and describe, the details of execution steps, as discussed in Level-N, and is aimed to develop each step into its simplest presentation form. The said "form" is simplified enough to clearly identify the personnel, locations, tools, and approaches used to carry out the forensic tasks, as well as the expected results, and can further evolve into the status of assignable units of task assignments.

After the completion of development, all bottom-level-dataflow in the digital forensic model is converted into the specifications of bottom-level-dataflow, and all resources, such as personnel, tools, devices, etc. can be listed and summarized to establish a digital forensic construction dictionary.



found during other forensic procedures, or failure of implementing the subsequent forensic procedure due to special causes.

Acceptance and handover (10.0): This model adds this procedure, which is a crucial and necessary action for when evidence data needs to be collected, preserved, and retrieved. Many forensic cases are suspended due to certain procedural issues, which arise from a lack of forensic technology, a need to collect new evidence, or other special causes. Under these situations, evidence data and mediate evidence must be properly, and safely, preserved for long periods of time, which demands complete acceptance of the integrity of evidence and handover procedures. In practice, evidence rooms are established by law enforcement units to provide long-term, suitable environments for protective and secure preservation and retrieval processes.

### The comprehensive forensic procedure

The comprehensive forensic procedure is the combination of the primary forensic procedure and the supported forensic procedure. To ensure the exactness and effectiveness of digital forensic results, the comprehensive forensic procedure is strongly recommended by this study as the best forensic procedure if actual conditions and resources permit. In practice, the supported forensic procedure may not be implemented, or only implemented due to shortages of budget, resources, personnel, equipment, or economies of scale. In such cases, the primary forensic procedure at least should be built into the implementation stage so that the digital forensic report will have a basic effectiveness of evidence.

### New feedback mechanism

This model proposes a creative feedback mechanism which is never shown in previous models. In this study, a new feedback procedure (9.0) is adopted as feedback mechanism, which can directly return to the procedure that is necessary to redo, but not only return to the previous procedure, as shown in Figure 2. In order to provide strict, admissible evidential forensic results, most research on digital forensics has pointed out that a feedback mechanism is required for the digital forensic procedure [1] [2] [3] [4] [5] [7] [8] [11] [15] [18] [20] [22]. To enhance the forensic requirements of the digital forensic procedure of any given stage, the feedback mechanism is a means of returning to a previous procedure, depending on the situation or data needed.

Pervious studies have indicated that the feedback mechanism can only return to the previous procedure one by one till the initial problematic one is found rather than being return to the initial problematic procedure directly. There is a serious shortcoming to this approach that is obviously very rigid and can not meet the diverse needs of the situation. The main

reason is each of the procedures with analysis and diagnosis can only return to its previous one and accept the request for its next one. For example, if the last procedure is found wrong, incomplete or without sufficient data in the very beginning of the forensic procedure occurred, it must be rigid to return to the previous procedure one by one till returning to the very beginning of the problematic procedure. This will cause waste of resources and inefficiency in forensics. Therefore, this model proposes the feedback procedure (9.0), which is very flexible and effective in solving this problem.

### Level-1 model development

Previous studies have only provided conceptual explanations, lacking detailed explanations regarding expression of the execution of details. The purpose of this level is to present, and to describe, how each forensic procedure is developed and processed. Each “process” in this level is presented by an arc block, and numbered in recommended sequence. The numbering principle is based on procedure numbering used in level-0, with one more digit. For instance, “4.1” means the first procedure of the fourth forensic process.

Figure 3 depicts a reference example of collection (4.0) procedure in the forensic procedure. The processing process may be designed linearly, where applicable, or in combination with the internal feedback mechanism, if necessary, for cases such as searching (4.2).

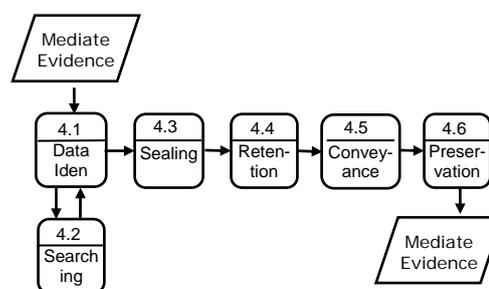


Figure 3 progression of “collection” procedure  
Source: This study

### Level-N model development; and continuing development until bottom-level-dataflow

This model development aims to subdivide and decompose necessary forensic tasks into their simplest presentation form, covering the simplest sources of data, implementation processes, and interim results. This form of presentation is conceptually referred to as a bottom-level-dataflow. In such cases, the simplest presentation form means that the tasks are already simplified enough for

individual operation, or individual assignments. As illustrated in Figure 4, the simplest presentation form is obtained after searching (4.2) is developed.



Figure 4 Forms of presentation developed into their simplest presentation form  
Source: This study

The key point of the development content of level-N is the description of the processing process. If any process in level-1 is still complex, it means that it is not yet developed into its simplest presentation form, such as data identification (4.1), as shown in Figure 5. In other words, if additional sub-processes are required by any process, the development needs to continue from level-2 to the next level, until all sub-processes are decomposed into their simplest presentation form and, regardless of follow-up, would continue to develop the number of levels, such as the bottom-level-dataflow, as illustrated in Figure 4.

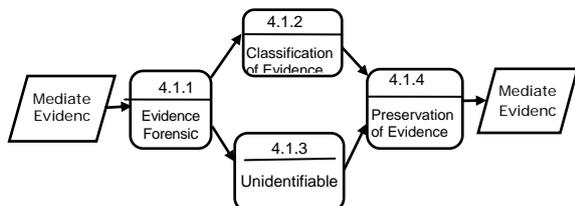


Figure 5 Decomposition diagram of sub-process  
Source: This study

From level-2 to the bottom level, the source of data and interim results would use a parallelogram symbol to represent the mediate evidence. The process described herein is also represented by an arc block. Similarly, for every additional level, corresponding numbers are added to the previous level, and the numbers in the same level are numbered sequentially.

**Specifications of bottom-level-dataflow**

When all procedural processes are decomposed into their simplest presentation form, the process is simplified enough to know how to execute these processes. In this level, the main purpose is to add forensic personnel, forensic tools, forensic site descriptions and forensic results to the previously developed bottom-level-dataflow, which is then converted to a presentation form of “assignable units of task assignments”. In this model, this form is conceptually referred to as the specifications of bottom-level-dataflow. In other words, the process can be described as an assignable, or an executable,

unit of task after the specifications of these factors are explained.

In this level, the forensic site is represented by a cubic symbol, the forensic personnel (including number of people) is represented by a triangular symbol, and the forensic tools, or method (including the quantity), is represented by a hexagonal symbol, as shown in Figure 6.

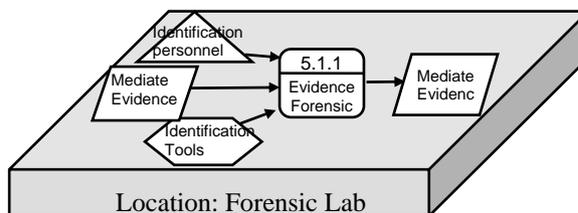


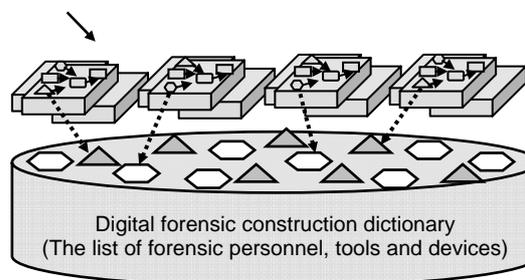
Figure 6 Specifications of bottom-level-dataflow  
Source: This study

Mapping from bottom-level-dataflow to specifications, then mapping to digital forensic construction dictionary

Another important problem is realizing the amount of resources required to meet forensic demands throughout the entire digital forensic process. Namely, which area of specialty, how many professionals, specialty tools, and equipment are in need of preparation? These are factors affecting budgetary planning, staffing, training, and equipment procurement scheduling of enforcement units. Thus, this study proposes a digital forensic construction dictionary for addressing the problems faced by the digital forensic practitioners.

A digital forensic construction dictionary aims to list types, quantities of all forensic task forces, tools, and any equipment necessary for the entire digital forensic process. As discussed above, these data for each individual process can be obtained from the specifications of bottom-level-dataflow and could be statistically collected and sorted, which is the perspective of a digital forensic construction dictionary, as shown in the lowest part of Figure 7. Table 2 is an example table of a digital forensic

Specification of bottom-level-dataflow



construction dictionary.  
Figure 7 Conversion diagram of digital forensic construction dictionary  
Source: This study

With the use of a digital forensic construction

dictionary, digital forensic practitioners can easily list and estimate the types and quantities of professionals, tools, and equipments needed, as well as the procurement time. When level-0 the comprehensive forensic procedure is fully developed, it is possible to obtain a digital forensic construction

dictionary, comprised of the fullest range of resources for the digital forensic process, and is therefore, referred to as an integrative digital forensic construction dictionary. It is also recommended by this study.

Table 2 Example table of digital forensic construction dictionary

Source: This study

Staffing requirements	XXX Table				
Task assignment Types of personnel	4.1.4	4.2.1	....	Total	Unit Price
Collector	X	X		X	X
Examiner				X	X
Analyst				X	X
Conveyer	X			X	X
....	...	...	...	...	...

Equipment requirements	XXX Table				
Task assignment Types of equipment	4.1.4	4.2.1	....	Total	Unit Price
Anti-magnet box	X			X	X
Digital sealing machine	X			X	X
Special disk drive		X		X	X
Data reproducer		X		X	X
.....	...	...	...	...	...

However, the digital forensic practitioners in different sizes of organization may find it difficult to establish an integrative digital forensic construction dictionary due to budget restrictions or limitations of scale. Therefore, this study suggests that practitioners should select their most necessary resources, according to an integrative digital forensic construction dictionary, and build a basic resource list based on their actual budget to meet their digital forensic processing needs. The preparation of a basic list of resources can facilitate smooth budgetary planning and procurement procedures as well as the fundamental digital forensic procedure implementation. It is referred to as a fundamental digital forensic construction dictionary.

### Discussion

The establishment of the digital forensic procedure can be regarded as the establishment of a forensic system. To the management level, the establishment of a "system aspect" is important; however, the practitioner is more concerned with how to handle each procedure and how to connect the processes in practice. In other words, previous researchers highlighted the discussion of the system's aspects (procedure level: level-0 in this model), but neglected the "executive aspect" (how to develop: level-1 to bottom-level-dataflow in this model). This study proposed a solution for the above situation. Thus, this comprehensive combination of system and executive aspects could be realized to join together the feasible framework. In addition, this model proposes a digital forensic construction dictionary for a detailed description of the requirements from a "resource aspect", making contributions to actual budgetary planning and procurement processes. The

three dimensions never shown in previous models at the same time can be clearly established from this model, which offers a decisive implementation of digital forensics.

A new system of digital forensics is proposed by this study, the comprehensive digital forensic procedure. While common forensic procedures are included in the comprehensive digital forensic procedure, as proposed by this study, any study or practitioner could add, or delete procedures where necessary, according their individual needs. Therefore, this model does not conflict with other procedural models proposed by other researchers, but allows for more flexibility and degrees of inclusion.

The viewpoint of digital forensic evidence data process flow in this study, does not contradict, or exclude, the procedural model viewpoints of past studies. In contrast, the proposed viewpoint not only includes the concept of procedural models but is able to explain, in detail, the descriptions of the interactions between the procedures and digital evidence data, as well as its processing objectives. In addition to systematically linking all of the digital forensic process activities, it is also adaptive in explaining the framework and details of digital forensic of different levels.

### Conclusions

This study proposed the expandable integrated digital forensic model, not only to present new concepts of digital forensics, but also describes, in detail, the methods of execution. This model can also provide a comprehensive basis for guidance and practical implementation steps for forensic practitioners, model guidance and practical

execution can be complementary. In the model every developed process can be noted in a uniform digital expression form, in order to promote understanding and facilitate sharing experiences.

Though this model seems to provide a static description method, different digital forensic practitioners can employ different procedural combinations, as based on various actual forensic missions offering different modus operandi, in order to achieve dynamic descriptions. In addition, since this model is presented systematically, with straightforward symbols, almost all digital crime cases can be described, and recorded, in digital forensics, thereby establishing a digital forensic library for knowledge management and sharing.

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