A Qualitative Theory for Crime Scene Analysis

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Abstract

Crime scene analysis is a discipline involving the identification and correlation of various actions that occur during a given incident. These correlations exist as both causal and temporal relationships between the various objects involved in the incident. Although the beliefs that guide crime scene reconstruction are relatively simple and very much a product of common sense, this paper outlines the underlying foundation of these beliefs in detail.

Keywords: crime scene reconstruction theory, multilinear event sequencing, event analysis, crime scene reconstruction, forensic science

Article Information

Received: 13 February 2015
Revised: 16 June 2016
Accepted: 13 July 2016
Published: 24 July 2016

Citation: Gardner RM. A Qualitative Theory for Crime Scene Analysis. *J Assoc Crime Scene Reconstr.* 2016;20:45-55.

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Introduction

Crime Scene Reconstruction (CSR), also referred to as Crime Scene Analysis (CSA), is a forensic discipline that seeks to identify as many objective statements as possible regarding what happened and in what order it happened during a given phenomenon–often some incident believed to be criminal in nature. This analysis provides an objective picture, although incomplete, that can be used to consider the more subjective information that develops during any criminal investigation. This subjective information includes two very specific aspects of the investigation: the testimonial evidence provided and the varying theories of the incident proffered. Crime scene reconstruction effectively allows for the evaluation of any statement or investigative hypothesis (either in whole or in part) and provides an objective way to try and decide if the statement or hypothesis is refuted or corroborated.

Crime scene reconstruction is accomplished by identifying, through an examination of the evidence and the context in which it is found, specific actions that occurred. This analysis seeks to isolate causal and temporal relationships between the actions. This process is accomplished through various methodologies (defined sets of procedures) that, if followed,

help to ensure an objective analysis. These methodologies have been described in various papers and books; however, underlying these procedures must be some basic belief, a theory that drives the analyst's behavior. As the author and Griffin described in a recent article:

> The scientific basis of any discipline is inherent in the behavior of the analyst. The analyst acts in furtherance of the analysis by measuring something or seeking out some specific criteria for evaluation because some empirical observation drives that behavior. This is the true essence, the science behind any forensic discipline. [1]

Hauk and Quarino commented on this relationship between theory and procedure as well, writing:

> If you take a measurement, you have to have a theory of some sort; otherwise, how would you know what measurement to take? [2]

Some authors have argued that procedures are unnecessary in crime scene reconstruction [3]. This belief seems counterintuitive, as it is the procedures that drive any analyst's behavior and thus ensure the analysis is truly scientific. But if the analyst is to accept any set of procedures as valid, they must first accept the theoretical basis behind those procedures and be confident of the completeness of those procedures. In 2007, the author along with Tom Bevel outlined the various historical themes and principles that drive the behavior of the crime scene analyst. In that article the general theoretical basis of crime scene reconstruction was described as "Nothing just happens." [4] This statement may seem simplistic, but this belief is based on the writings of all of the various authors, over the nearly 100-year history of crime scene reconstruction. This theory can also be correlated to one particular historical figure, Edward Oscar Heinrich, a physics professor at the University of California, Berkeley. The Wizard of Berkeley, as Heinrich was known, earned his name by assisting the police in many complex investigations of the time. In his 1958 biography, Heinrich offered the following as an explanation for his underlying belief behind crime scene reconstruction:

> This work of mine is not mysterious. It's a matter of understanding the scientific concepts of ordinary phenomena. Rarely are other than ordinary phenomena involved in the commission of a crime. One is confronted with scrambled effects, all parts of which separately are attributable to causes. The tracing of the relationship between isolated points of fact, the completion of the chain of circumstances between cause and effect, are the highest functions of reason… [5]

In Heinrich's opinion, the remnants of the crime scene (the artifacts and the context in which they are found) could all be explained as a function of cause and effect relationships, all of which were temporally related.

Thus actions lead to other actions, many of which produce effects that are observed by the crime scene analyst. If the analyst can isolate distinct actions and correlate the connections between any of them (to any level), the complexity of the incident is better understood.

It is important to recognize first that a crime scene analyst is attempting to explain a unique incident. There is only one instance of any given crime, it is a unique and rare phenomena. Without a crime scene reconstruction, no objective standard exists with which to compare anyone's particular beliefs about the incident. No matter what level of data is available; the information derived from CSR effort (the analysis of that data) provides some level of understanding of both the cause-effect and temporal relationships between these actions. This knowledge becomes the objective standard to which investigative theories can be compared.

A second consideration requires that we distinguish between that being evaluated and the basic approach to conducting the evaluation. That which the analyst examines (the incident itself) is highly convoluted, requiring detailed analysis, the use of every aspect of science available and often demanding complex logical arguments to resolve. The manner in which one approaches this analysis (crime scene reconstruction methods) is at its core simple and based on our common experiential based understanding of how our world works - nothing just happens; things and events are interconnected. Thus the concept of how we conduct CSR is simple in theory,

but exceedingly difficult in practice due the complexity present in that which we investigate.

Due to the common sense aspects associated with CSR beliefs (one thing leads to another), little effort has been directed at refining the theory of CSR within the criminal investigation arena. But there was on-going theory development in another arena, and that effort is directly applicable to the discipline of crime scene reconstruction. The area of interest is systems safety investigations also known as failure analysis. Remember that the crime scene analyst is attempting to explain a unique and rare phenomenon (the specific incident under investigation). Every incident being investigated is itself unique. Granted they involve many predictable scientific cause and effect relationships (e.g., the manner in which blood behaves under a given force, the behavior of a bullet in flight, the transfer of genetic information) which appear in many incidents, but the incident in question occurs once and only once.

Failure analysis deals with objectively explaining unique and rare phenomena as well. These concepts are utilized by a wide array of organizations including the National Aeronautics and Space Administration, the National Transportation Safety Board, and the Federal Aviation Administration to evaluate incidents of concern. Air crashes, industrial accidents and similar situations investigated by these organizations are one-time unique events. Granted, there are many air crashes under similar circumstances; but any given air crash occurs under a unique set of individual circumstances, just as crimes do. A precursor to current failure analysis efforts was the development of Multi-Linear Events Sequencing (MES), pioneered by Ludwig Benner in the 1970's. Benner explained his foundational theory in this way:

> My hypothesis generation method is based on the premise that the functioning of our universe and its constituent parts reflects a continuum of interacting events. Events, in this context, are used in the sense that someone or something does something (actor + action = event.) Each event influences one or more events, which follow that event in time. It is the precede - follow logic of the related events that provides the key to the hypothesis generation method. [6]

Note that no difference exists between Benner and Heinrich's beliefs. Each is articulated in slightly different words, but they are effectively one and the same. This similarity is most evident when considering methodology. Theory drives the practitioner's methods, and when compared, Benner's MES methodology mirrors, almost step for step, certain crime scene reconstruction methodologies. [8]

These prior efforts in both CSR and Failure Analysis are sufficiently insightful to maintain and direct the course of modern crime scene reconstruction methods. Both operate from the same understanding of how our world operates in a macro perspective; which we all recognize based on our common human experience. Nevertheless, recent attacks on all aspects of forensic science by the law profession culminated in the release of the National Academy of Sciences report: Strengthening Forensic Science in the United States: A Path Forward.

One clear challenge coming out of the NAS report was the demand to revisit, validate, and refine theories and principles associated with the various forensic disciplines. This challenge raises the question: Beyond the obvious precepts and common-sense aspects of CSR beliefs, can a more detailed CSR theory be described?

Purpose

The purpose of this paper is to better articulate the underlying theory of crime scene reconstruction. Certainly the simplicity of our belief, that "nothing just happens" is an idea understood by all rationale human beings. It is a matter of everyday human experience that actions are related to one another and things do not change without a change agent:

- If I don't push on the brake, the car doesn't stop.
- If I walk off a cliff and do not stop, I will fall.
- If I don't turn the faucet knob, water will not flow.

But calls to the common sense aspects of our beliefs are insufficient as a function of science. Science demands that we isolate our understanding, define our beliefs in detail and present the means by which those beliefs can be challenged (the concept of falsifiability). Thus the ideas presented here will not alter our

approach to valid crime scene reconstruction techniques. This paper simply presents those beliefs in a more detailed manner, the tenets of which can then be challenged by anyone.

Discussion

In the context of both Heinrich and Benner's explanations, the statement that nothing just happens can be better articulated as:

> Given a series of actions associated to a specific incident, any given action has a unique causal and temporal relationship with every other associated action.

This statement is the underlying theory of crime scene reconstruction. For purposes of this article:

- An incident is the phenomena being investigated. Each incident is made up of a series of associated actions.
- An action is a change in state of some particular actor (that actor may be either an animate or inanimate object)
- An object is a physical object, not a point particle. It has mass and is three-dimensional, thus we can exclude quantum considerations.

For this theory to be correct, we must believe the following set of axioms:

1. Every object is unique.
2. While it exists - an object must exist continuously in both time and space.
3. Every point of an object's existence (what is described as its world-line) is connected to some other point of its world-line until it is converted into something else.
4. For any temporal value of an object's path through space-time that follows some other value of the object's path, that temporal value is greater than any preceding temporal value.
5. Every value of an object's path through space-time is unique.
6. To affect a change in state of an object (to create an action) there must be a cause.
7. An effect cannot precede the cause.
8. A change in state of an object can only occur as a function of some interaction with another object(s) or by coming under the influence of a fundamental force (e.g. gravity, electro-magnetic forces).
9. In order to interact, the spatial and temporal position of the objects must overlap in some way and/or the object must exist spatially and temporally within the influence of a fundamental force.
10. Every action associated with an object has at least one prior action that influenced it.
11. Any given two actions associated to an incident have a unique causal relationship.
12. Any given two actions have a unique temporal relationship.

These axioms present the means of disproving the theory. If any one of these axioms can be shown to be invalid, the theory itself is invalid as written.

As Benner effectively described, unique phenomena theory is concerned with objects that are changing as a result of some interaction. In MES an actor plus an action is known as an "Event Block," or as Event Analysis describes it, an "Event Segment," which for purposes of this paper are described as "actions" [6, 7]. In order to understand these actions, the analyst must first recognize the involved objects. The theory thus begins with objects.

Axiom 1 — Every object is unique. An object (any three dimensional artifact we encounter in a scene) is consistent with itself, and it remains consistent with itself until converted into something else. Objects certainly change over time, but whatever the object, it remains "that object" or the resultant unique constituent parts that made up that object. For example a complete cartridge, through firing, becomes the bullet or perhaps bullet fragments that were originally present in that cartridge, the powder expelled is still the propellant that was present in that cartridge (granted it becomes indistinguishable from other propellants, but it has not changed; what was in the cartridge is now in the environment), and the expended cartridge case remaining is still the cartridge case that was present in that unique complete cartridge.

Just as each object is consistent with itself, any given object is not equal to any other object.

A cartridge case may well be similar to many other cartridge cases, but each is unique in their existence. The specific molecules that make up one case are discrete from the molecules that make up any other case. Thus every object is unique.

Axiom 2 — While it exists, an object must exist continuously in both time and space. In every modern physical theory an object was understood to have three spatial dimensions that could be referenced to a given manifold. In other words, it existed somewhere in space. A classic example would be to describe an object in a crime scene in relation to some Cartesian coordinate system (e.g., a basic manifold set by the limits of the interior of the room). Thus we might say a certain point of the object lies 2 meters right on the Y axis, 3 meters forward on the X axis and 2.5 meters up on the Z axis. Space however was long considered a construct in which time passed; time itself was considered as an independent feature.

Herman Minkowski introduced the concept of four-dimensional space-time [8]. To Minkowski, a space-time vector consisted of four independent values (four mutually orthogonal vectors) where t or x^0 is the time vector and x^1, x^2, x^3 were the typical spatial dimensions. Minkowski's idea survives today in the highly tested theories of both Special and General Relativity [9].

All current physics theories describe space and time as a continuum in which events occur. As referred to in physics an "event" is simply an occurrence that takes place at some instant. As Ellis describes:

> Your birth was an event. JFK's assassination was an event. Each downbeat of a butterfly's wings is an event. Every collision between air molecules is an event. The set of all possible events is called space-time. [10]

During any object's existence we can reduce the interval between any two points in the time vector to as small a value as we desire, but that interval will still have a value. And as it has some temporal value, Minkowski's ideas tell us it also has a spatial value. This set of continuous moments of existence for any object defines its trajectory through space-time. This path is typically referred to as the object's world-line [11].

A given object has a discrete history; while it exists, it must exist somewhere, and this demands that there is a value for both its spatial and temporal position.

Axiom 3 — Every point of an object's existence is connected to some other point of its existence. From the time of an object's creation to its conversion into something else, it traces a continuous path through space-time, existing in all four dimensions at all times of its existence. Each point connected to another point in the manifold. This includes from its initial creation to a point forward in time or from its conversion/destruction to a point backward in time. Even after conversion (e.g., the complete cartridge breaking down into constituent parts) the world-lines of the constituent parts are connected to the objects original world-line. As we are dealing primarily with observable physical objects (macroscopic objects) we can ignore concerns over the quantum oddities associated with particles (objects at or below the Plank level).

This world-line history of an object demands first that the object exists, second that for any given moment in that existence there is a spatial and temporal position for the object, and finally that every slice of the object's world-line is connected to some other given value of the object's world-line.

Axiom 4 — For any temporal value of a world-line that follows some other value of the object's world-line, that temporal value must be greater. Although a continuing philosophical question, movement through space-time appears to be a one-way trip. As Eddington first described, it is an arrow moving forward to the future [12]. Thus relative to our perception of and understanding of our universe, time can only move one direction and temporal values can only increase along the world-line, they cannot decrease.

Axiom 5 — Every value of an object's world-line is unique. An object is itself unique, and as it is three-dimensional, the object must exist at some specific point in time and space throughout its existence.

An object at rest in space will remain in some particular spatial dimension within the manifold (some given value of x^1, x^2, x^3). Although the object can always remain spatially stationary, the object is in constant motion in the temporal dimension (the value of t or x^0). It cannot remain stationary in time.

So an object can exist in the same space over any given period or return to that space, but it can only exist in one place at any one time and the temporal value can never be repeated. This demands that every value of an object's history (every set of values for t, x^1, x^2, x^3) is absolutely unique - if for no other reason than the temporal dimension.

CSR is concerned with identifying what this paper defined as "actions", changes in state of the various objects involved in the incident. These changes demand some influence acting on the object.

Axiom 6 — To create an action (to produce some change in state of an object) there must be a cause. The physics concept of an "event" is some unique point along an object's world-line [10]. A physics event is merely an instantaneous moment in the object's history. An action as described here, represents an object undergoing some change in state.

Actions are slightly different from physic events in that the former represent a more macro component than intended by the physics event. For example, if the action were "bullet fired," in effect this would consist of a series of physics events (the near instantaneous moments) of the trigger being pulled on the weapon, the powder igniting in the cartridge case, the pressure building in the cartridge case, and the bullet being propelled down the barrel by the pressure.

So actions are always inclusive of at least one of these physics events and more likely a series of these instantaneous events (e.g. trigger pulled, powder burned, pressure increases). The only difference between the two is in the manner of considering them. They are either absolutely instantaneous moments resulting in a change in state of the object or they are a series of connected moments of the object(s) world-line resulting in an observable change in state. Regardless, actions in the context of CSR are effectively interchangeable with a physics event, representing nothing more than a particular moment on the object's world-line.

The proof of this axiom lies primarily in Newton's 1st law of motion, which demands that in order to effect a change in state of an object (to cause it to stop doing what it was doing and do something else) some force must act on it. Forces cause accelerations (changes in position) of objects. Any change in state of an object is the result of some acceleration of the object within its manifold, occurring at some particular moment on the object's world-line.

Axiom 7 — Effect cannot precede cause. Changes in state cannot occur until the introduction of a change agent. A basic principle of CSR is pursuing causal connection; what exactly is interacting to cause a change in state. Recognizing the change agent and its related change forces a temporal order between the two; demanding cause, followed by the effect. Recognition of this causal connection allows the analyst to identify the actions that must precede or follow a given action. Many of these connections are direct cause and effect relationships, but direct causal relationships are only part of the picture. As the paper will discuss, ancestral/hierarchal causal relationships (chains of actions that connect divergent paths of actions) exist as well. These ancestral relationships also allow the analyst to understand temporal order [13].

Direct or hierarchal, these relationships demand a specific order of actions associated with a given incident.

Axiom 8 — An action (a change in state of an object) can only occur as a function of some interaction. Newton's laws of motion tell us that to accelerate any object in any manner (thus cause a change in state) there must be some force. Without the presence of a force, the object simply would not change (e.g., blood would remain in the body, fingerprints would not be deposited, objects would not be displaced). The nature of the force acting on the object may be an interaction with another object(s), where world-lines intersect in space-time (e.g. a bullet striking a surface causing a ricochet in the first and creating a defect in the second) or it may be a fundamental force influencing the object (e.g., radiant heat causing pyrolysis in an object that leads to combustion).

Of course, nothing prevents both from acting to cause this change in state. Consider the flight path of a ballistic object through Earth's atmosphere. When fired, a bullet is sent along a particular vector moving in a given direction and at some particular speed. On earth and exposed to the atmosphere and gravity well produced by the Earth's mass, both objects and a fundamental force define the bullet's path. The bullet's mass interacts with air molecules in its path altering its speed over time (objects interacting as their world-lines intersect). At

the same time, throughout its flight the mass of the bullet is affected by gravity altering its path downward towards the center of the earth (an object under the influence of a fundamental force).

Axiom 9 — In order to interact, the spatial and temporal existence of objects must overlap in some way - or - the object must exist spatially and temporally within the influence of a fundamental force. If the change in state of an object occurs as a result of an interaction with another object, the two objects must come in contact with one another. This demands that their world-lines (their spatial and temporal positions within the manifold) converge at some point.

The trajectory of the bullet previously described defines its world-line once fired, as well as any resulting new world lines created; for instance assuming the bullet disintegrates each part of the original bullet begin their own unique world-line from the termination of the complete bullet's world-line. The interaction of the bullet with the air (a convergence of their two world lines) alters the object's trajectory. When the bullet meets another object (e.g. strikes a surface or a victim) the convergence of the two objects' paths may lead to deformation of the bullet and/or redirection of the bullet's path, once again altering its world-line.

If the object's change in state occurs as a result of an interaction with a fundamental force, then the object's existence must coincide within the force's influence (it must exist somewhere within the spatial and temporal influence of the force involved).

Fundamental forces are active throughout the phenomena that analysts examine. Some are in effect at all times and cannot be escaped (e.g., a blood flow on a surface moves under the influence of gravity). Such forces are always considered in relation to the various objects encountered. Other fundamental forces may or may not impact on some aspect of the phenomena. Consider the example of radiant heat in a fire. Radiant heat is a basic fundamental force (e.g., electro-magnetic force/ photons). Objects that are in direct proximity at the time of the radiant heat source may ignite because they come under the influence of this force. Objects more distant from the fire may not be affected at all.

From its creation to its conversion to something else, as a unique object (e.g. a bullet, a cartridge case) it traces a singular path through space and time, interacting with various other objects and coming under the influence of various forces. All of these interactions influence the object's path.

Axiom 10 — Every action has at least one prior action that influenced it. While an object exists, it exists somewhere, and that existence is continuous throughout the life of the object; no object simply appears. There are no circumstances of instantaneous appearance; the object's creation and/or presence at a scene itself are a product of some series of prior actions in history. All object world-lines are connected to some other world-line.

Even if we were to presume an object as remaining spatially stationary for an extended period between actions, no matter how lengthy that stationary history, ultimately the object's existence must be explained as a function of some interaction by other objects at some prior point in history.

Thus all actions were influenced by some prior set of actions. In crime scenes there are no primordial actions; some set of conditions/ actions leads to every other action. Each action recognized in the reconstruction is connected to some other set of action(s) that preceded it.

Axiom 11 — Any two actions associated to a given incident have a unique causal relationship. Causal connection is one of the most basic principles in crime scene reconstruction, but it can be one of the more difficult ideas to recognize. The reason for the difficulty is simple; in CSR the analyst is only able to identify a small number of specific causal relationships. Sufficient observable data does not exist to allow a complete and absolute understanding of all of these relationships (e.g., a complete understanding of all associated world-lines interactions). The analyst's inability to provide the empirical evidence of every causal relationship between the associated actions in a specific case situation does not presuppose that none exist.

All of the actions associated with a given incident share either a direct causal dependence (Action A directly results in Action B), or they share a hierarchal/ancestral causal relationship (a unique causal chain).

Consider Figure 1. Action B independently causes Actions C and D. Action C causes

Action E and Action D causes Action F. There is no direct causal connection between Actions E and F, but there is a resulting causal chain. Without Action B, neither Action E nor F will occur. Lewis proposed this idea of causal chain, where actions may not share a direct causal dependence, but they do share some ancestral relationship [13]. This second form of causal relationship, the causal chain, when recognized is a powerful tool to the crime scene analyst. It allows analysts to set relative order to highly divergent strings of actions that share no direct causal connection.

or inanimate object). Thus the actions (*A*) taken by Murderer 1 and Victim 1 are designated in the figure as M1A_x and V1A_x. Actions taken by Murderer 2 and Victim 2 are designated as M2A_x and V2A_x.

Assume then that actions M1A_a and M2A_a correspond to the two killers passing through the apartment complex door at the same time. Action M1A_a is followed by action M1A_b, where killer M1 breaks down the door of his victim's apartment. This directly precedes and causes victim V1 to flee to the interior bedroom, action V1A_a. These two actions have a direct causal dependence. These actions set in motion a series

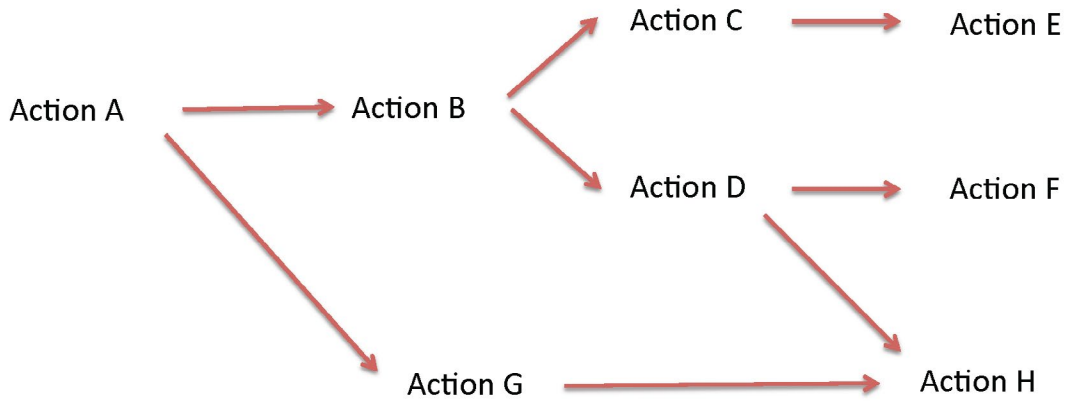

Figure 1: Causal relationship between objects involved in any given incident is either direct as in the case of Action A, which directly leads to Actions B and G. Or they are in the form of causal chains as in the case of Action E, which must be preceded by Actions A, B and C. Note that divergent causal chains can set the stage for future actions and leading to a re-convergence as in the case of Action H. Here the two causal chains A-B-D and A-G bring about the conditions that allow Action H to occur.

Consider the following scenario:

> Scenario 1: Two serial murderers, completely independent of one another, randomly choose the same apartment complex in which to commit their murders. Neither knows of the others' actions, intent or even existence. On the same night Murderer 1 (M1 in Figure 2) goes to the 1st floor of the complex where he commits the murder; the second Murderer (M2 in Figure 2) chooses an apartment on the 2nd floor of the complex. By pure coincidence, they enter the apartment complex at the exact same time, through the same door, passing each other as they continue on their independent courses of action. See Figure 2.

For the sake of simplicity, Figure 2 limits the actions to activity by people (remember a CSR action is a change in state of either an animate

of additional direct causal actions, where some action on the part of the murderer and victim (M1 or V1) leads to corresponding action(s) by either.

The causal dependence/causal chain idea is relatively evident in the actions M1A_b and V1A_a. The action of Murderer 1 forcing entry through the door and all of its associated actions precedes in whole the response of the victim fleeing down the hall to the bedroom. The resulting series of direct causal connections become a unique causal chain. In other words, A causes B and immediately precedes B; B causes C and so on.

Although this causal chain is itself a weaker form of causal relationship, such relationships are present throughout the entire incident. Consider the path represented by action M1A_c. Let's assign this to the action of killer M1 closing the door behind him, which has no

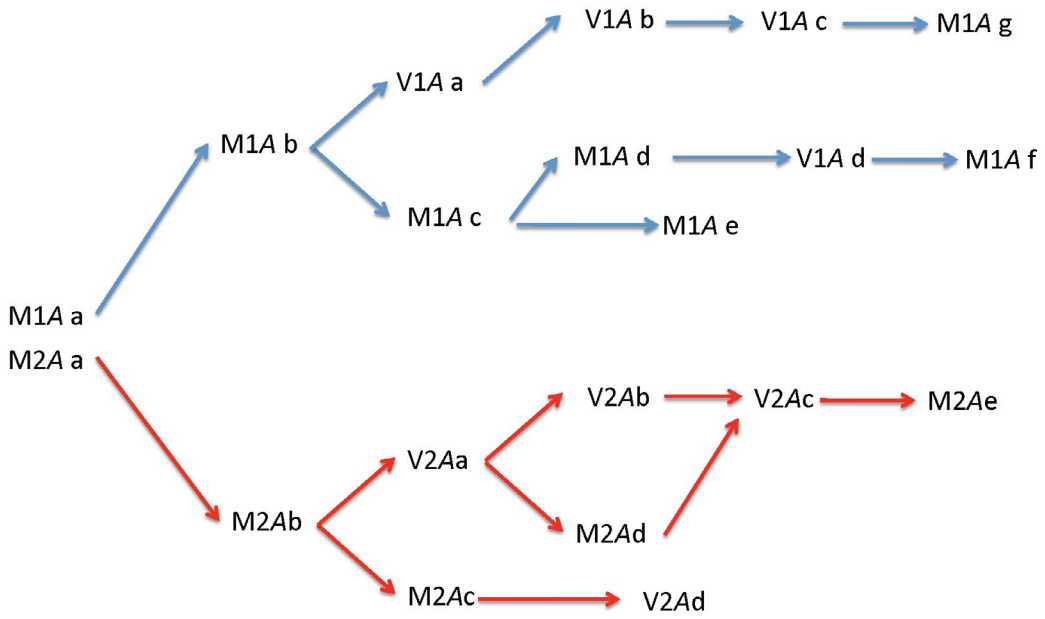

Figure 2: Causal chain is a difficult concept to visualize, but it exists throughout any incident. Highly divergent paths such as $M1A_d$ and $V1A_b$ share a convergence at some point in their history, specifically in this case $M1A_b$. Proximity (either spatially or temporally) alone does not demand causal connection, as in the case of $M1A_a$ and $M2A_a$, which in the example are the two hypothetical killers passing each other on their way to their respective scenes.

direct relationship to the victim's actions of fleeing down the hall ($V1A_a$). Action $M1A_c$ will lead to additional actions at later points (e.g., reopening the door to leave) and thus produce a divergent path from the path produced by the victim's response. Each interaction can create a new divergence point between the various actions, resulting in an exceedingly convoluted arrangement. In this arrangement, once past the divergence point no direct causal relationships exist between the different branches. But like a family tree, these divergent branches/paths must diverge from some earlier point.

Consider the path defined by the actions $V1A_a$, $V1A_b$, $V1A_c$ and $M1A_g$. This chain of actions cannot occur unless action $M1A_b$ occurs. In the same fashion, the actions of the killer $M1A_c$ and $M1A_e$ create separate divergent paths. There is however no direct causal connection that exists between these two divergent paths. Yet because they are associated, they share some ancestral causal connection in the preceding chain of actions, specifically in this case the actions leading back to $M1A_b$.

Somewhere in the preceding chain of actions leading to any two divergent paths of actions, there exists some connecting action (e.g., $M1A_b$ in Figure 2). Think of this in its simplest form: they came, they killed, and they left. If Murderer 1 never comes through the door of the complex, then none of the resulting paths or their associated actions inside the scene can occur. If the actions are associated, this ancestral connection will exist no matter how distant in the past it may be.

Note that many of these divergent paths will set the stage for future actions during the incident. Divergent pathways of causal chains can later converge as in Figure 1, where the divergent paths of Actions D and G set the stage (converge) allowing Action H to occur. The result is that any graphic representation of a crime scene reconstruction tends to be a highly complex and convoluted document, depending on the level of information available to the analyst.

It is important to recognize that mere spatial or temporal proximity between two actions does not in and of itself create a causal association between actions. For example, the hypothetical actions associated to the second killer weave their own distinct causal paths. His actions share no causal relationship, direct or otherwise, to the actions associated with the first murderer. Even the actions of the two killers passing through the apartment complex door together have no causal relationship. That they occurred in spatial and temporal proximity to one another is pure coincidence.

This particular aspect of the example demonstrates one of the greatest concerns in CSR, that of contextual bias. Given this scenario of two murders in the same complex on the same night, an analyst might make a causal connection between the two incidents. Two murders in the same location at the same approximate time would likely be viewed as improbable and the analyst would probably attempt to link the two incidents. Contextual bias by the analyst is problematic and must be controlled when evaluating causal relationships. Only valid, strongly evident causal connections should be utilized in the analysis.

The value of recognizing direct causal dependence is that it allows the analyst to link and order certain actions.

The value of the ancestral relationship is also significant. Consider that in CSR only a handful of actions are ever defined or understood resulting in many holes in our understanding of the incident. Effectively, in any CSR effort the analysis identifies a number of divergent chains of actions. Consideration of the causal chain often allows the analyst to develop some level of sequencing between divergent paths of actions and with that information understand if a particular hypothesis is supported or refuted.

Axiom 12 — Any given set of actions will have a unique temporal relationship. Whereas causal connection between associated actions is more convoluted in explanation and recognition, temporal relationship is an unmistakable idea. The various interactions between objects that occur during any incident result in changes in state of the object – what we have described as actions. These actions occur at distinct points in space-time, a particular point on the object's world-line. As discussed, spatial position can change, remain consistent, or be repeated, but temporal position is always unique to the given manifold. All of the objects the analyst is concerned with share the same manifold, thus their temporal values are uniquely related to one another.

Once again the limitations of analysis will never allow recognition of each and every temporal relationship between the actions. We simply can't identify the distinct moment of every action as it relates to every other action - but that relationship does exist. This idea leads to another central theme of crime scene reconstruction – the principle of chronology. Temporal relationship manifests itself in two ways in CSR. This relationship may be exact (e.g. absolute chronology) where we can set a specific time to an action or actions, or it may be more ambiguous (e.g., relative chronology) where we recognize that some action precedes, is simultaneous to, or follows some other action. This latter relationship of relative chronology is the far more common form of temporal relationship identified during any crime scene reconstruction.

Conclusion

Acceptance of these axioms leads us back to the theory:

> Given a series of actions associated to a specific incident, any given action has a unique causal and temporal relationship with every other associated action.

To disprove any one of the described axioms is to disprove the crime scene reconstruction theory. Whether one accepts these statements as axioms or as theorems provable through theoretical physics, they accurately describe the physical world in which we live.

The objects we encounter in crime scenes are unique. While it exists as a recognizable object, it traces a singular and distinct path through space and time. Objects interact with other objects or come under the influence of fundamental forces resulting in changes in state in the object – thus, causes lead to effects. The analyst through detailed analysis of the scene and objects associated to the scene recognizes some of these cause and effect relationships as "actions," specific moments during the incident where objects are undergoing change. These actions are unique in terms of why, where, and when they occur. Combined they represent a unique history (partial though it may be) of the incident that has value to the investigation and the court.

Recognition and acceptance of this theory provides validation of the basic procedures utilized to conduct a crime scene reconstruction. Current CSR methods seek to identify actions and to recognize any causal and temporal relationships that may exist between the actions. The theoretical basis provides the discipline with a rationale and pathway to follow during the analysis. It is not necessary that the

CSR analyst become a physicist to apply these principles, but any valid methodology used for crime scene reconstruction must be based on this foundational belief.

The CSR analyst recognizes and accepts that they will never identify every action occurring during a given incident, let alone describe all of the causal and temporal relationships. But these relationships do exist and some are identifiable through the evaluation of both the physical evidence and the context in which that evidence is found. Crime scene reconstruction is simply recognition that if sufficient data exists, it will allow the analyst to understand the nature of some of these unique actions and relationships.

This understanding allows the analyst to put some level of order to the known actions and to start to define what was or was not possible during the incident in question. The analyst and/or the court can use this knowledge to refute or corroborate various ideas and theories proffered during the investigation.

The ideas described in this paper have no direct affect on current crime scene reconstruction efforts, but they do establish that crime scene reconstruction cannot be based on "because I said so" or founded solely on "my experience and training". Using this theoretical mindset valid CSR effort seeks to define objective causal and temporal statements about the various objects involved in the incident in question.

Acknowledgments

My thanks to Ludwig Benner and Christine Ramirez for their assistance and insight.

References

1. Gardner RM, Griffin T. The Foundations of the Discipline of Bloodstain Pattern Analysis – A Response to the Report by the National Academy of Sciences. *J Forensic Ident.* 2010; 60 (4): 479.
2. Hauck MM, Quarino L. Saving Us From Ourselves: Re-creating Forensic Science. Forensic Mag. 2008; 5(1): 39.
3. Nordby JJ. Scientific Foundations of Crime Scene Reconstruction: Introducing Methodology to Mayhem. Boca Raton (FL):CRC Press; 2013, xxvii.
4. Gardner RM, Bevel T. Theoretical and Practical Considerations in Crime Scene Reconstruction, *J Forensic Ident.* 2007; 57(6): 891-911.
5. Block E. The Wizard of Berkeley. New York (NY): Cocwood and McCam; 1958, 42-32.
6. Benner L Jr. Accident Investigations: Multilinear Events Sequencing Methods. *J Safety Research.* 1975; 7(2), 67-73
7. Gardner RM. A Comparison of Event Analysis and Multi-linear Events Sequencing Techniques for Reconstructing Unique Phenomena. *J Assoc Crime Scene Reconstr.* 2010; 16(1): 1-9. Available at: http://www.acsr.org/journal-archives/abstract/a-comparison-of-event-analysis-and-multilinear-events-sequencing-techniques-for-reconstructing-unique-phenomena
8. Walter S. Minkowski, Mathematicians, and the Mathematical Theory of Relativity In Goenner H, Renn J, Ritter J, Sauer T, editors. The Expanding Worlds of General Relativity (Einstein Studies, volume 7). Boston: Birkhauser; 1999, 45-86. Available at: http://scottwalter.free.fr/papers/einstd7.pdf
9. Petkov V. Minkowski Spacetime: A Hundred Years Later Fundamental Theories of Physics. New York: Springer Science & Business Media; 2010, 165.
10. Ellis SD. Chapter 2: Particles and Symmetries. University of Washington: 2014. Cited on 11 Feb 2015. Available from: http://courses.washington.edu/partsym/14Spr/Preface_14.pdf
11. Petkov V. Minkowski Spacetime: A Hundred Years Later Fundamental Theories of Physics. New York: Springer Science & Business Media; 2010, 286.
12. Eddington A. The Nature of the Physical World. Cambridge (UK): University Press; 1928, 36-63.
13. Lewis D. Causation. *J Philosophy*. 1973; 70(17): 556-567.