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Positional Prediction of Individuals Present In a Crime Scene

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Abstract: *The scientific study/interpretation of bloodstain patterns at a crime scene, provide invaluable evidence for sequencing, reconstruction of events that might have occurred at the crime scene. the authors have tried to amalgamate the works that have particularly contributed towards scientific advancement in the documentation, interpretation of bloodstain patterns, thereby putting forth the research initiative that they (i.e. the authors) intend to undertake within the multidisciplinary domain of bloodstain pattern analysis. Authors try to overview the entire crime scene process.*

Keywords: *Transfer stain, Cast-off pattern, Impact spatter, Saturation stain, Bloodstain patternanalysis, Fluid mechanics.*

I. Introduction

As per the National Crime Record Bureau, Ministry of Home Affairs, violent crimes accounted for roughly 24.4 % of the total number of crimes reported and hence recorded in the year 2013[1]. Delhi (54.4%) reported the highest rate of violent crimes, followed by Assam (42.3%), Kerala (40.5%) and Arunachal Pradesh (37.9%) as compared to 24.4% at All-India level[1]. The National Crime Record Bureau categorizes violent crime under the following heads

Murder, Attempt to Commit Murder, Culpable Homicide not amounting to murder, Rape, Kidnapping and Abduction, Dacoity, Preparation and assembly for dacoity, Robbery, Riots, Arson and Dowry Deaths[1]. The FBI's (Federal Bureau of Investigation) Uniform Crime Reporting (UCR) Program, has defined offenses which involve force or threat of force as violent crime[2]. The FBI Uniform Crime Reporting Program states that violent crime is particularly composed of four offenses - murder and non-negligent man-slaughter, forcible rape, robbery and aggravated assault[2]. As per the 'Crime in India Report 2013'published by the National Crime Record

Bureau, there has been a subsequent yet persistent increase in violent crime rate over the last 20 years[1]. While police investigation of 72.8% of IPC (Indian Penal Code) cases was completed, 27.2% of such cases remained pending at the end of the year 2013. 84.8% of IPC cases were found to stand pending in court at the end of year 2013[1].

Once crime is reported, the investigation phase commences. The investigation phase in itself can broadly be classified under the following 3 heads - 'Defining the Crime Scene', 'Processing the Crime Scene', and 'Information collection from and about the crime scene'[3]. The information in the form of testimony, hearsay evidence, documentary evidence, real and original evidence is used for reconstruction of criminal events and thereby placement of such evidence before the juridical system to draw well analyzed conclusions[4]. So collection andinterpretation of evidence does play an integral role in shaping the proceedings of a criminal case[4]. It is this process of 'interpretation of evidence' that we intend to revolutionize by way of this research work[4].

We intend to use bloodstain pattern evidence obtained from a crime scene to probabilistically predict the relative positions of the victim/s, perpetrator/s, and bystander/s (if any)using Bayesian networks with strong reasoning based on the concepts of physics , fluid mechanics, mathematics and medical science.

'Crime Scene Reconstruction' based on different sorts of relevant evidence forms an integral part within the juridical setting. In order to aid the reader/s in understanding how our research initiative fits in within the crime scene reconstruction procedure, at the very onset we would like to acquaint the reader/readers with some of the terminology that we intend to use over the length of this project work.

1. B) Important Terminology

1.1. Crime – Violent Crime

Given that we intend to work in the area of 'Violent Crime' that particularly involves blunt force trauma, it might be helpful to know a 'wide' definition of crime and how crime is defined within the Indian juridical setting.

The Oxford Dictionary defines 'Crime' as 'an action or omission which constitutes an offence and is punishable by law'[5]. The Uniform Crime Reporting program conducted by the Federal Bureau of Investigation (FBI) divides offences particularly into 3 broad categories based on the seriousness of the crime.

They are – Part I offences, Part II offences and Other Offences[2]. Part I offences as the FBI records are serious crimes that occur with regularity in all areas of the country and are likely to be reported to the police[2]. Part I offenses include Criminal homicide, forcible rape, aggravated assault, burglary (breaking or entering), Larceny-theft (except motor vehicle theft), motor vehicle theft, arson[1]. Part II offences include, other assaults (simple), Forgery and Counterfeiting, Fraud, Embezzlement, Stolen property: buying, receiving, possessing, Vandalism, Weapons: carrying, possessing etc., Prostitution and Commercialized vice, Sex offenses (except forcible rape, prostitution, and commercialized vice), Drug abuse violations, Gambling, Offenses against the family and children, Driving under the influence of an intoxicant, Liquor laws, Drunkenness, Disorderly conduct, Vagrancy. Other offenses include Suspicion, Violations by juveniles (under the age of 18) of local curfew or loitering ordinances, runaways by juveniles (under the age of 18) taken into protective custody under the provisions of local statutes[2]. Figure 1 provides a graphical description of the crime classification system endorsed by the UCR program conducted by the FBI[2].

In coherence with the crime definitions put forward by the UCR program, the National Crime Record Bureau, India, categorizes violent crime under the following heads – Murder, Attempt to

Commit Murder, Culpable Homicide not amounting to murder, Rape, Kidnapping andAbduction, Dacoity, Preparation and assembly for dacoity, Robbery, Riots, Arson and Dowry Deaths[1].

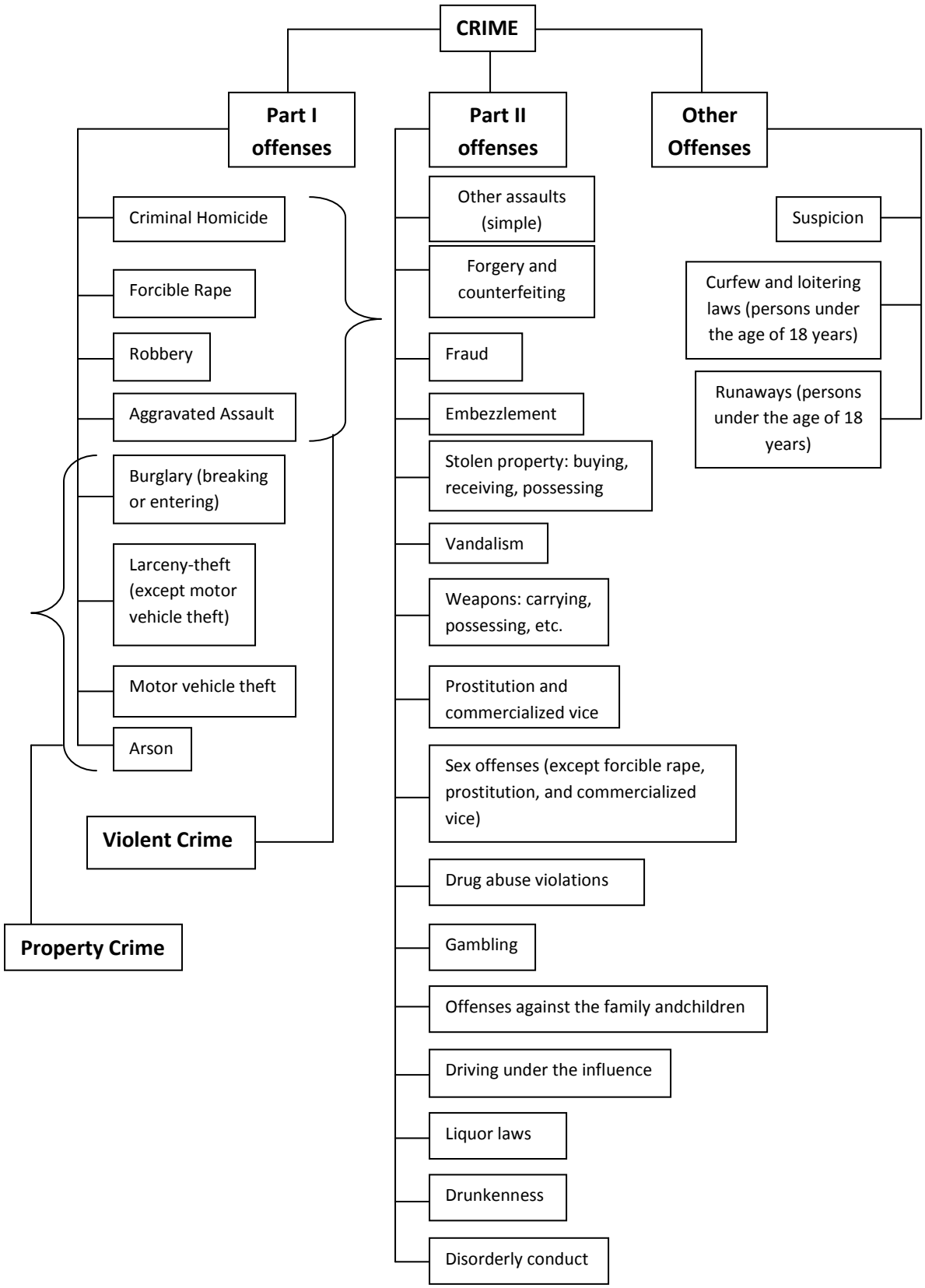


Figure 1: A Crime Classification Chart developed by the United Crime Reporting Program

1.2. Bloodstain Pattern Analysis

Of the various sorts of physical evidence such as hair, fiber, soil-particle, pollen-grains, tool-marks, bite-marks etc. that are used for crime scene reconstruction. We particularly intend to study one particular type of evidence commonly referred to as bloodstain pattern evidence which is often overlooked in a crime scene involving bloodletting events. The Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN) defines 'Bloodstain Pattern' as 'a grouping or distribution of bloodstains that indicate through regular or repetitive form, order, or arrangement the manner in which the pattern was deposited'[6]. J.J. Nordby, Ph.D., D-ABMDI defines 'Bloodstain Pattern analysis' as 'the scientific study of the static consequences resulting from dynamic blood shedding events'[7].

The distribution, shape (regular or irregular) and size of the bloodstain pattern on the clothing, skin , shoes , accessory of the victim/s, perpetrator/s, bystander/s , on the room walls, ceiling , floor, other objects in the scene can help reconstruct the sequence of bloodletting events that might have occurred in a crime scene. Stain pattern evidence often helps analysts estimate the number of blows struck, test the credibility of the statements put forward by the witness/s, victim/s, perpetrator/s within a juridical setting.

II. The Juridical Setting – Criminal Complaint trial

Now that the reader/s has a clear idea of which particular subsection of crime as also which particular sort of physical evidence we particularly intend to deal with, it would not be out of place to provide a graphical overview of how criminal offense is dealt with within the Indian juridical setting. Figure 2 summarizes the Juridical setting relevant to trial of a criminal complaint within the Indian juridical system[8].

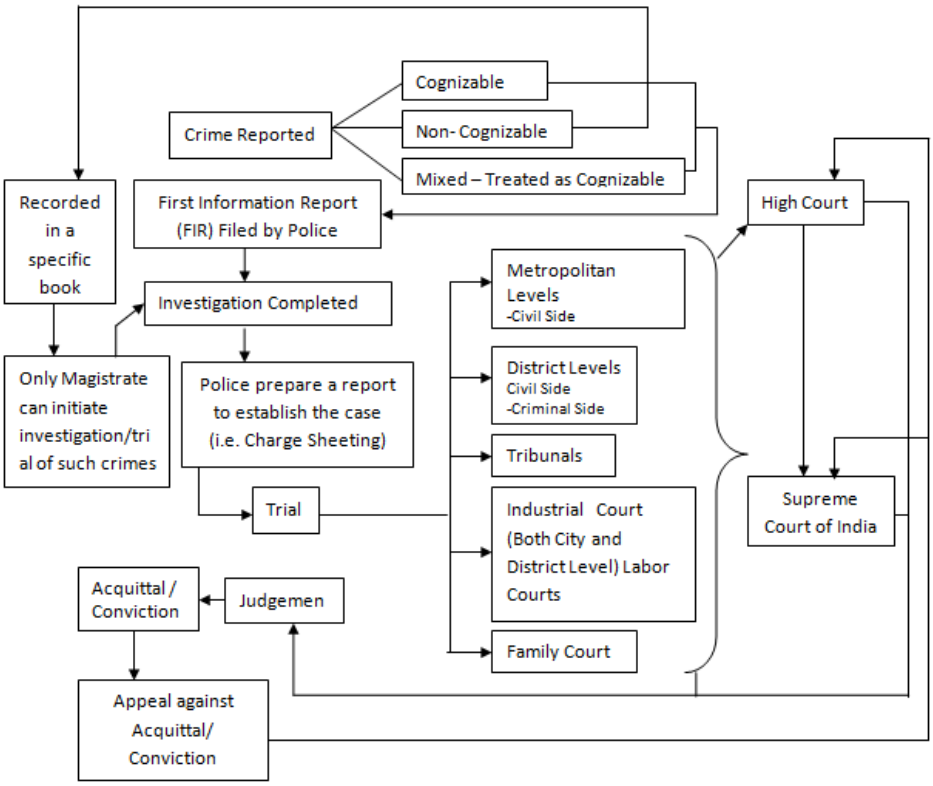


Figure 2: Flow Chart describing the trial of a criminal complaint within the Indian juridical setting[8]

The research work is particularly aimed at improving the process of crime scene investigation and hence reconstruction. Once a complaint is made, based on the crime type reported (refer Figure 2), the criminal proceedings that take place can broadly be classified into 3 basic phases - Investigation, Inquiry and Trial[8]. Figure 3 provides a graphical overview of the process of criminal case proceedings within the Indian juridical system[8].

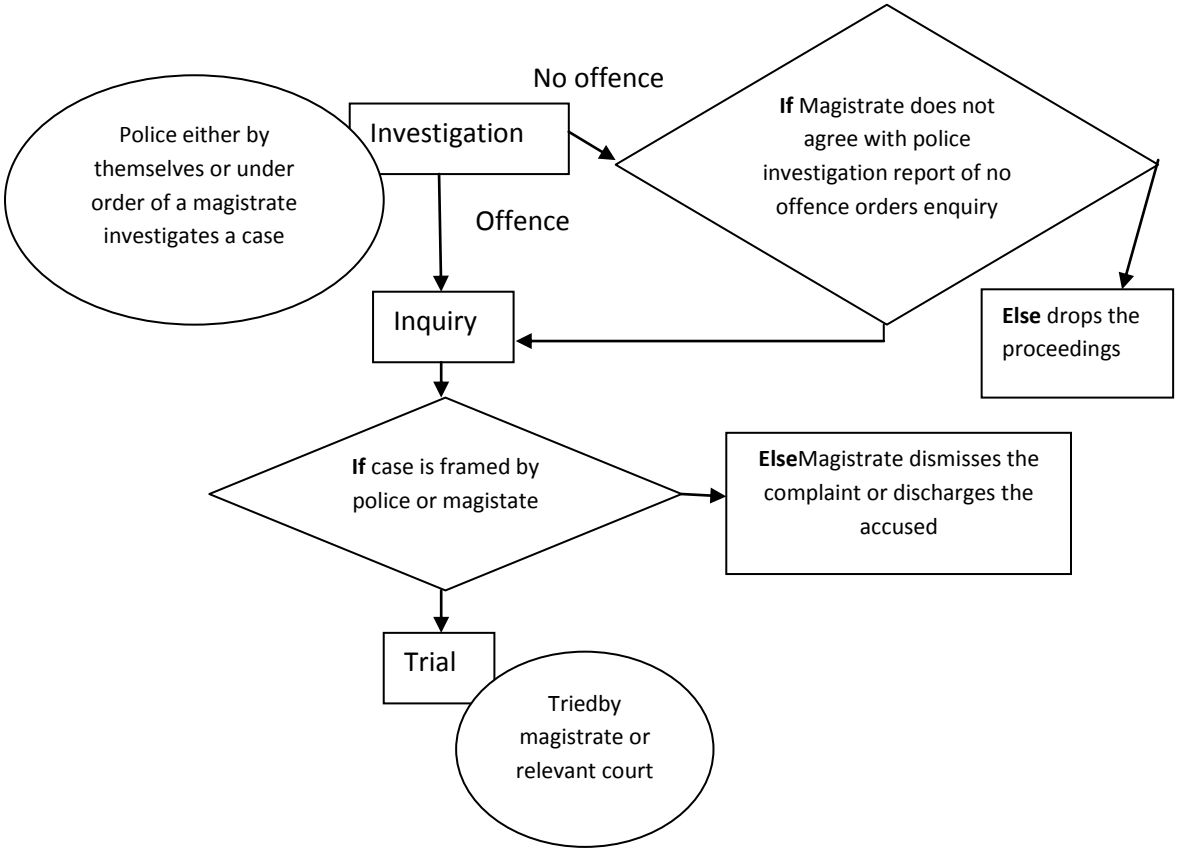


Figure 3: A flowchart documenting how a criminal case is processed within the Indian juridical system[8]

III. Crime Scene Investigation and Reconstruction

Crime Scene Investigation and thereby Reconstruction in its turn particularly involves 3 basic phases(refer Figure 4). They are,

- Defining the Crime Scene
- Processing the Crime Scene
- Information Collection from and about the Crime Scene[3]

Defining the crime scene refers to identifying the activity areas relevant to a particular criminal event[3]. The Primary Crime Scene is the area where the original crime occurred. The Secondary Crime Scene comprises of the subsequent crime scenes[3]. The size of the crime scene can further be classified as Macroscopic and Microscopic[3]. While Microscopic focuses on specific type of physical evidence at thecrime scene, Macroscopic refers to one particular crime location composed of many microscopic crime scenes[3]. In defining the crime scene, it is of utmost importance to understand the type of criminal offense that has been committed at the scene[3]. It can range from homicide, robbery, rape or an admixture of all. In analyzing evidence, it often stands integral to know the physical location of the crime scene (i.e. Indoors, Outdoors, Vehicle etc.)

Once the Crime Scene is broadly defined, the next phase of the Investigation process deals with 'Processing of the Crime Scene'. At the very onset, the Crime Scene Investigator establishes contact with the Law Enforcement Officer in charge of the crime scene. Also he/she makes a list of other people such as other law enforcement officers, coroner's personnel, public safety personnel, civilians, newspaper reporters etc. who have or have had access to the crime scene in question. The next step towards processing a crime scene is Securing the scene by use of police line tape or other means in order to prevent unwanted access to the scene by casual passerby, people with malicious intentions etc. The scene is secured in order to leave all evidence at the crime scene undisturbed by wandering individuals. Once secured, the scene is subjected to initial overall survey by investigating officials. At this point, the officials leave all evidence undisturbed and develop initial theories based on apparent understanding of the crime scene. The officials also mark out potential evidence in the initial walk through phase. The first responders as also enforcement officials take into account the entry /exit points in the scene that require attention. This phase also requires the officials to make a list of equipments and precautions that the officials would need to take in order to document as also search the crime scene.

The crime scene is thoroughly documented by way of Notes, Videotaping, Photographing and Sketching[3]. Once clearly documented, systematic search patterns are used in order to avoid missing out on any

piece of physical evidence present at the crime scene[9]. The different search patterns that are used to search a crime scene have been graphically documented in Figure 5[9].

3.1. Evidence – Legal Perspective

The third phase of the project particularly deals with collection/securing of evidence from a crime scene. The legal system classifies evidence or rather 'relevant' evidence as – Testimony, Real evidence, Hearsay evidence, Original evidence, and Documentary evidence (refer Figure 6)[4]. Evidence is termed 'relevant', when the facts that are subject to prove or disprove in a court of law amount to

- Facts in issue, i.e. those which need to be proved by one party;
- Relevant facts, i.e. those which tend to prove the facts in issue;
- Collateral facts which may for example affect the credibility and/or competence of a witness[4].

Evidence based on its use in understanding a crime scene can broadly be classified into two broad groups – Associative Evidence and Reconstructive Evidence. Associative evidence, in its turn, can also be used for reconstructive purposes. While Finger-mark, Fingerprint, Foot-mark, DNA(from Hair, body fluids), Ear-mark, Bite-mark, Handwriting can particularly be used as associative evidence for uniquely identifying an individual, evidence such as Firearm, Shoe-mark, Fibers, Paint, Glass, Tool-mark, Soil, Drugs, Fire debris, Explosives, Pollen Grain help, Bloodstain Pattern help in crime scene reconstruction.

Given that this Research work is particularly aimed at interpretation of Reconstructive Real (read Physical) Evidence, it would not be out of place to present a classification of the different types of Reconstructive Evidence that are used for crime scene reconstruction based on how they contribute to the reconstruction process. The different types of Reconstructive Evidence are Temporal/sequential evidence, Directional evidence, Positional Evidence, Action and Associative Evidence[10]. Bloodstain Pattern evidence can be used for sequencing events at a crime scene. Again, it can be used to trace the direction in which a body was dragged. In addition it can also be use to draw useful conclusions about the relative position of the victim/s, perpetrator/s and bystander/s (if any) in a crime scene. Stain patterns can be used for predicting the probability of events that might have occurred at a crime scene. Bloodstain Patterns cannot in particular be associated with an individual. DNA analysis of blood samples, blood serology test can be used as associative evidence for uniquely identifying an individual.

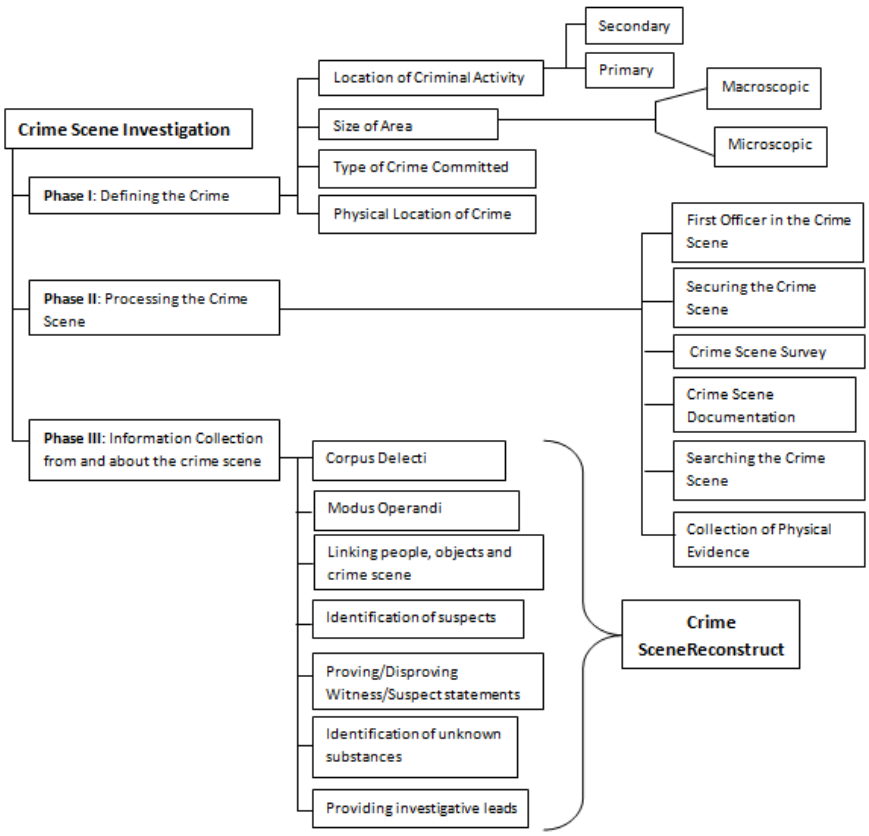


Figure 4: Crime Scene Investigation – a broad overview [3]

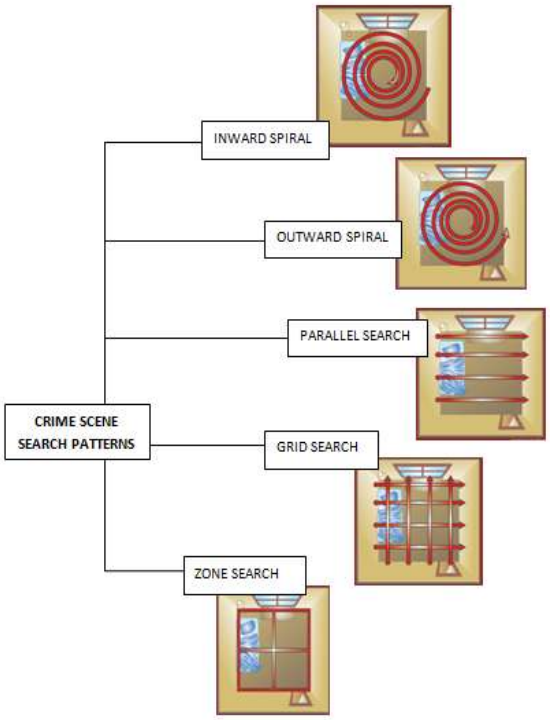


Figure 5: Search patterns used for collecting evidence from a crime scene[9]

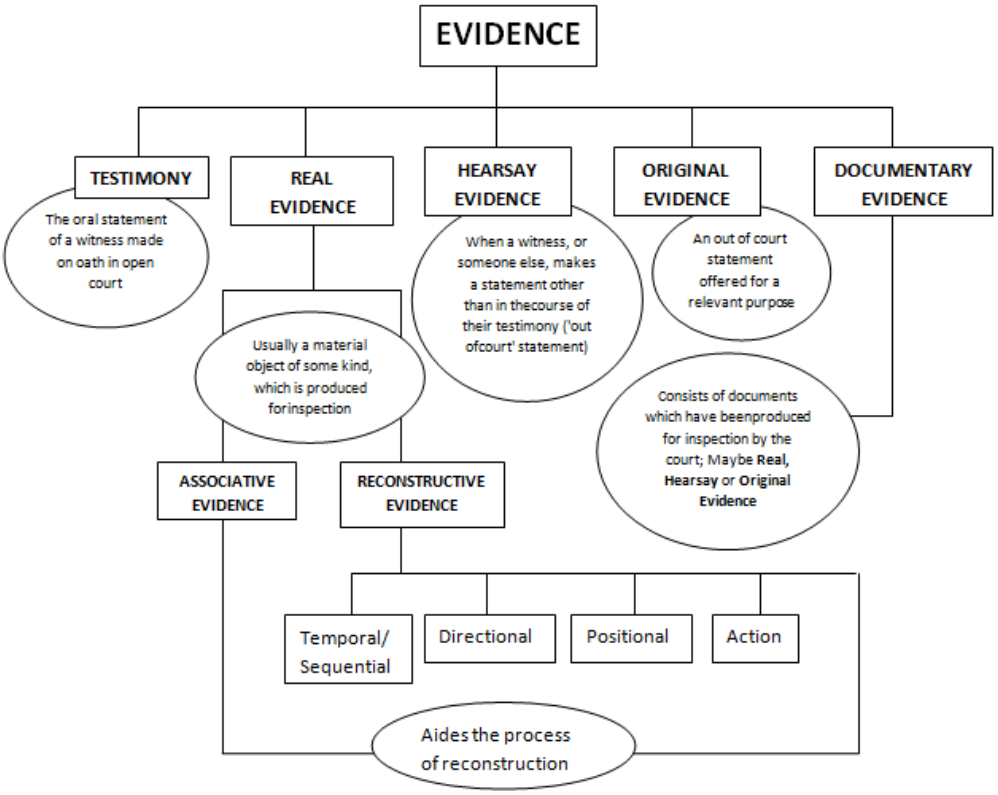


Figure 6: Evidence classification table[4]

IV. Overview of the Research

Based on the significant areas of research identified by the Scientific Working Group of Bloodstain Pattern Analysts (SWGSTAIN) and in order to add more objectivity and scientific reasoning to the entire process of Crime Scene Reconstruction, the following objectives were outlined.

1. To document the variation in the formation of drip stain patterns owing to different angle of impact, fall height, ejection aperture, volume of blood, air flow, humidity; on non-absorbent surface (say plain printing paper).
2. To document how the drip stain patterns vary when the same are created on different sorts of fabric in terms of visibility, stain shape, stain size, drying time based on factors such as absorption ability of the fabric, texture of the fabric, position of stain fall, volume of blood etc.
3. To establish a statistical/scientific methodology to evidently distinguish between swipe and wipe bloodstains on non-absorbent surfaces.
4. To develop a scientific technique to enhance bloodstain patterns on difficult surfaces (by difficult surfaces we mean surfaces on which the stain isn't clearly visible to the naked eye).
5. To develop a window based software that enhances the stain pattern on difficult surfaces given a particular image.
6. To analyze and report if it is possible to build an automatic bloodstain pattern analysis tool based on the taxonomy based classification chart provided by Bevel and Gardener. If at all it is possible, we intend to build such a tool using machine learning concepts, else we shall provide a report with practical examples on the constraints of devising such a tool.
7. To develop a database of recreated crime scenes and how fabric stains, hammer imprint and shoeprints etc. could be related to the position of a victim, bystander, and perpetrator by calculating the varied distances, angles at which each one was positioned at the time of occurrence of the criminal act.
8. To statistically map how formation of stain on fabric (particularly cloth) of an individual could be mapped with his/her position in the crime scene using Bayesian networks.
9. To develop a method to sequentially arrange the different set of probable events taking into account bloodstain patterns together with other circumstantial 'relevant' evidence and assign a probability to each of the sequence sets based on a diverse extensive database, to start with 6000 cases strong.
10. To analyze and report the acceptance/admissibility of the bloodstain patterns in the Indian Court of Law in discussion with Judges , and other relevant criminal law practitioners.
11. A report clearly stating with scientific evidence, that no information is being added or removed from the evidence when enhancing the pattern evidence on difficult surfaces.
12. To analyze and report the reliability of other forms of pattern evidences such as shoeprints, bite-marks, tool- marks for reconstruction of a crime scene.
13. To device a window based tool that generates a 3D representation of a crime scene as suggested by a pattern analyst (particularly).
14. The tool shall be made compatible with all common operating systems.

V. Research Methodology – an overview

1. At the very onset, we intend to create a database of drip stains on non-absorbent paper and thereby record how the stain patterns vary owing to difference in flow aperture, height of liquid column, angle of impact, fall height, paper creases, temperature and humidity. [Fresh pig blood was preserved by addition of anticoagulant as per requirement. All samples were prepared with blood thoroughly mixed with anticoagulant]. We suggest use of pig blood for the experiment since it is quite similar to human blood[11][12].

2. Dataset of Blood drip patterns shall be created using fresh pig/porcine blood that will subsequently be treated with two different types of anticoagulants (Warfarin (orally administered) and Heparin Injection (intravenous)) and the effects of different dosage of the anticoagulant medications on the stain pattern on non absorbent paper surface would accordingly be recorded by varying the angle of impact and fall height. The day temperature and humidity shall also be recorded during the experimentation by the use of a hygrometer. A statistical analysis highlighting if there is a statistically significant difference in the stain patterns cast when the dosage of anticoagulant is varied shall be carried out.

3. By using the amount of anticoagulant that almost accurately mimics the stain patterns created by fresh pig blood, drip staining shall be done on different sorts of fabrics. Non-absorbent (for.eg.non-absorbent paper, flooring marble) and absorbent/porous surfaces(for eg. Fabrics) record different stain patterns even when similar physical mechanisms are employed to create the stains and that it is often more challenging to analyze stain patterns on fabric we intend to create a database of fabric stains in order to interpret the stains formed on the cloth of the perpetrator/s, victim/s and bystander/s(if any) . The fabrics can be particularly divided into 3 basic types. They are – Fabrics from natural fibers, Fabrics from man-made fibers, Fabrics for special uses (Refer Figure 7).

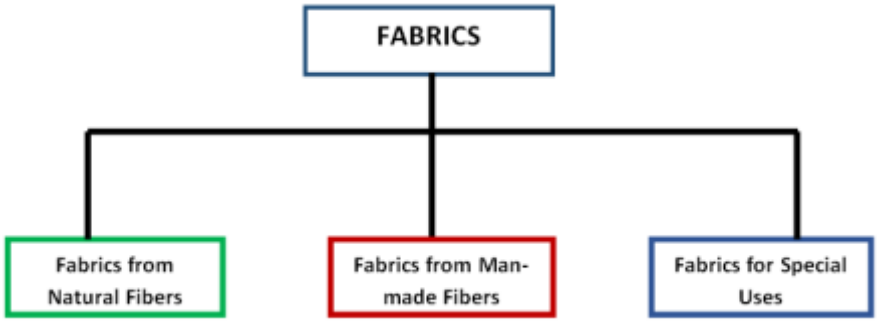


Figure 7: Basic Classification of Fabrics

4. The Fabrics from Natural Fibers (Refer Figure 8), Fabrics from Man-made Fibers (Refer Figure 9), Fabrics for Special Uses(Refer Figure 10) can further be subdivided into certain sub categories.

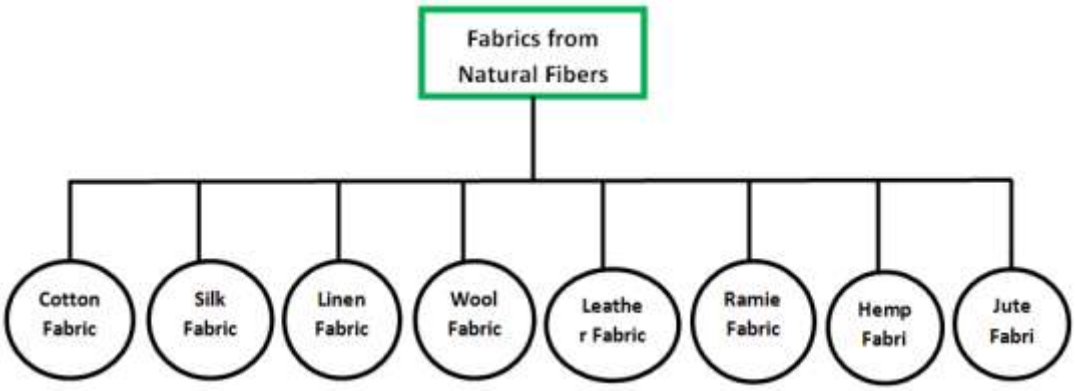


Figure 8: Classification of 'Fabrics from Natural Fibers'

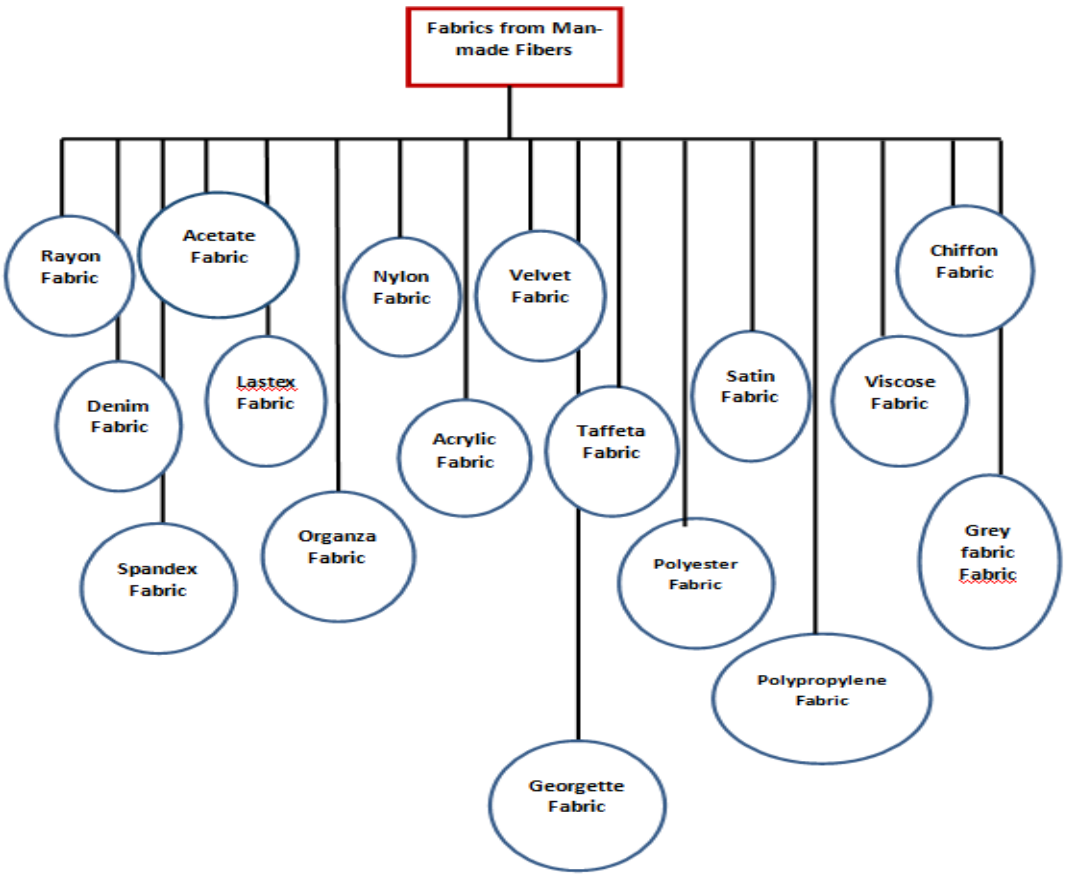


Figure 9: Classification of 'Fabrics from Man-made Fibers'

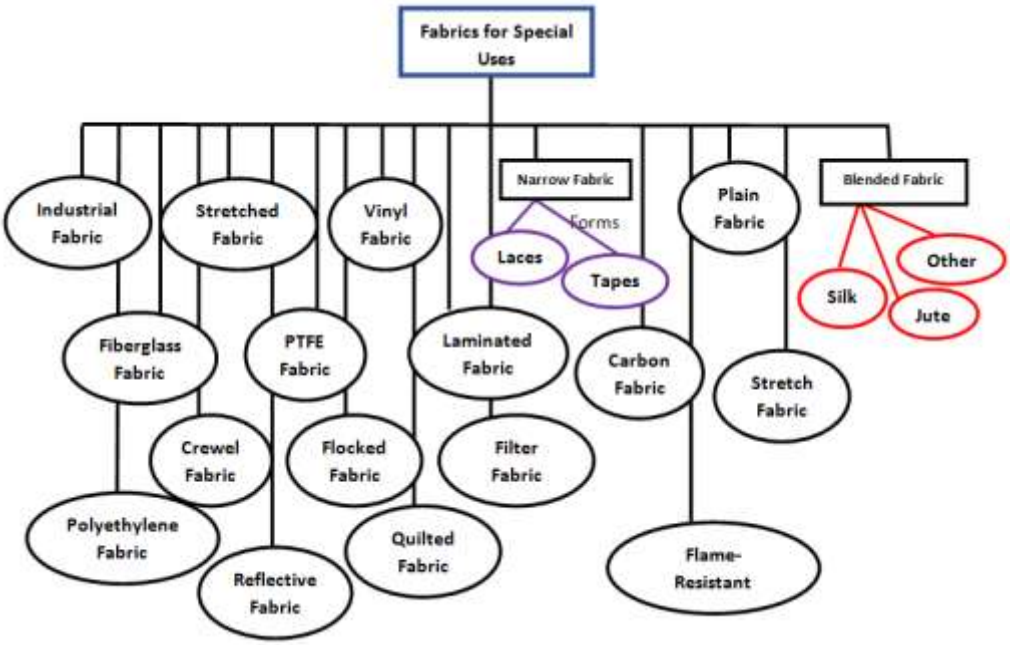


Figure 10: Classification of 'Fabrics for Special Uses'

Again each particular type of fabric can further be divided predominantly into two types – woven and knitted based on the weave of the cloth. We take the weave of the fabric into consideration because it has been previously noticed that the fabric type, weave of the fabric, position and volume of blood dropped influence the stain pattern formed.

For each fabric type, fabrics of four shades in particular are obtained. They are – white, gray, maroon, black. The shades may vary depending on the availability of the cloth in a particular shade, variance due to weave of the cloth, natural color of the fiber etc. We intend to stain two light colored fabric pieces and two dark colored pieces, to record how the color of the fabric affects visibility of stains to the naked eye.

Also we plan to use 3 different types of the same cloth – new, worn out (washed 8 times), sweat stained cloth washed 2 times, to record the same type of stains. From previous research we expect these different types of clothes to have very different stains although the stains might have been dropped using the same mechanism, under similar temperature , humidity and wind condition keeping the volume of liquid dropped , blood column , fall height, angle of impact constant .

5. Using different feature extraction and feature selection algorithms we intend to create a window based tool that can enhance the stain patterns irrespective of the color of the target surface(absorbent and non-absorbent surface) on which the stain was cast, cloth creases, and lighting conditions. However, the capability of the tool shall be restricted to analyzing images that are taken absolutely parallel to the surface on which the stain was formed. The reason for this being that, in bloodstain pattern analysis stain photographs are always taken parallel to the surface on which the stain is formed to avoid distortion in stain dimension owing to angular placement of the camera.

6. A dataset of wipe and swipe bloodstain patterns formed on non-absorbent surfaces (such as non absorbent paper surface, non absorbent floor surface, non absorbent wood surface etc.) shall be developed and an attempt shall be made to understand if there are any marked stain characteristics that can help analysts to distinguish swipe patterns from wipe patterns. Whether the difference (if any) between the two sets of stains statistically significant shall then be analyzed using t-test, correlation significance values.

7. A comparative study of the two bloodstain pattern classification systems put in place by Bevel and Gardener and Sutton and Kish shall be performed thereby aiming to analyze whether a window-based tool can be developed to automatically classify the different types of stains abiding by either of the two classification tables. If not, why it cannot be done, shall be explained with samples and scientific reasoning .If at all it can be done, the possible technical pitfalls shall be outlined.

5.1. Some of the possible pitfalls that are already present are ----

1. Bloodstain patterns are very fragile evidences that can be easily distorted, contaminated by careless footsteps, other environmental factors in a crime scene.

2. Different surfaces react differently to the same volume of blood being poured with the same velocity from the same height, at the same angle of impact using the same physical mechanism. That is to say, apart from

absorbent and non-absorbent surfaces, there are also stark differences in stain patterns between cloth pieces of different absorption capability.
3. Superimposed stains are difficult to judge and hence separate out for a human analyst owing to unwanted overlapping, distortion of the two stains. More so for a system, due to the large variability in the possible stain patterns
4. Presence and Absence of blood in a crime scene are both equally relevant, difficult for software to trace out its cause of relevance.
5. With due help from authorized law enforcement agencies (state police, army) and scripted court proceedings we intend to re-create primary (i.e. Location of the original criminal activity)(refer Figure 11) crime scene and the different sort of blood stains we could see particularly on different sorts of fabrics, floor, ceiling, walls, ground, both indoors and outdoors in a violent crime scene by use of a range of murder weapons (eg. Axe, Knife, Screw-driver, stick etc.).

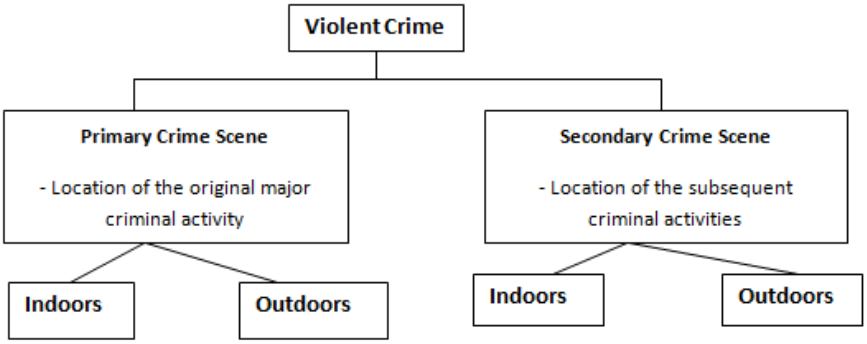


Figure 11: A graphical representation of crime scene classification

a) In the very beginning, we intend to document the stain type we can see or might expect to see on the clothes of an individual when he is a victim, perpetrator or a simple bystander in the event of a head hit of a victim using a stick, rod, axe etc. (The instruments of head hit shall be decided in discussion and study of court proceedings of several violent cases that have so far been solved) in an indoor setting. Based on the velocity of hit, stain type on cloth of an individual, number of hits, distance between the victim , perpetrator and bystander, relative position of the three at the time of hit, movement of any party before probable subsequent hits, direction of movement of weapons and people, room temperature, humidity, room dimensions, person height , weight ,using Bayesian networks, correlation and regression we would try to probabilistically infer the position of an individual (victim, perpetrator, bystander(if any)). While Figure 12 provides a three dimensional view of head hit, Figure 13 documents some of the possible positions of a victim, perpetrator and bystander in a crime scene at the time of first head hit in 2 dimension.

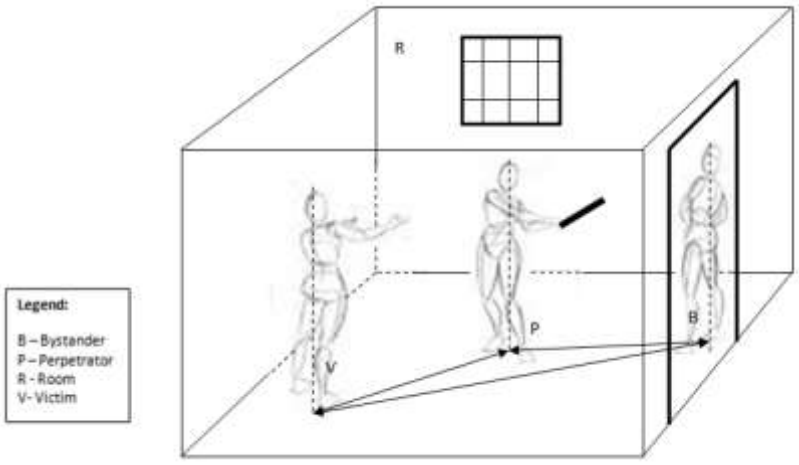


Figure 12: A 3 dimensional representation of a head hit scenario indoors (Blood stains haven't been marked in the 3D representation)

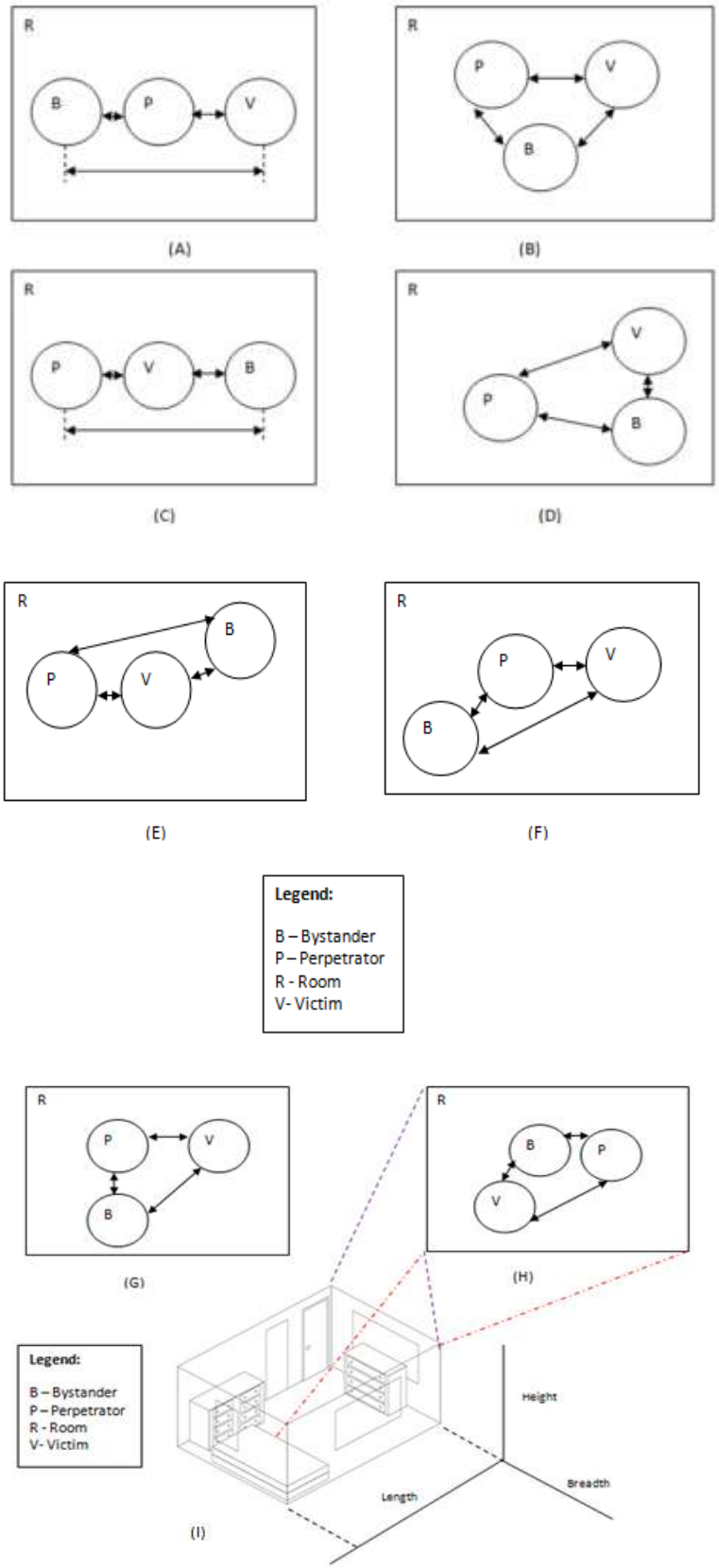


Figure 13: (A-H) 2 Dimensional representation of the position of a victim, perpetrator and bystander (if any) along with their relative positions represented by double headed lines, (I) Figure I represents the 2D representation of a 3D room. In all the Images, B represents the position of the Bystander, P represents the position of the perpetrator, R represents the room and V represents the Victim (refer Legend). Similar images can also be generated in an outdoor environment.

Head hit by use of different instruments can further be classified as displayed in Figure 14(A). Figure 14(B) displays how the information from a crime scene head hit event can be used for part/full reconstruction of crime scene.

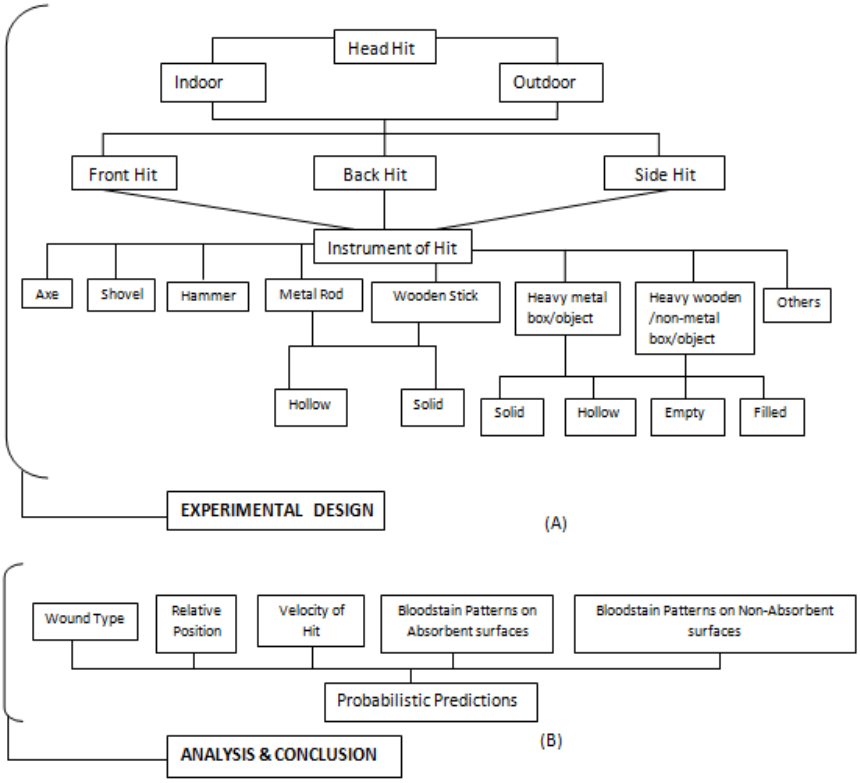


Figure 14 (a) Instrument of Hit and Figure 14 (b) Probabilistic Predictions

b) The second stage shall record the staining observed on the walls and ceiling as a result of subsequent head hits without change of position of any of the 3 individuals in the room and with subsequent change of position of the three individuals in one way or the other during the hit. The differences in the pattern formation on the walls and on the ceiling shall be recorded, thereby documenting the changes in position/movement that caused the differences in pattern.
c) The third stage shall record the head hit staining on the surroundings in an outdoor environment, based on the same positioning of the victim, perpetrator and bystander. The outdoor position shall be selected based on case study and in discussion with police staff who investigate crime scenes. An area study on which could easily be extended to other outside framed crime scenes would be an ideal area for experimentation.
d) A crime scene dataset with special emphasis on bloodstain patterns shall thereby be created containing recreated real crime scenes and thought out probable crime scenes to aid the presentation of bloodstain pattern evidence in a juridical setting
e). A window based tool shall then be developed that shall allow the end user (law professionals, police, forensic analysts) to draw up a room or an outside arena (probable choices shall be predefined). It shall facilitate the concerned individual to mark out different stain patterns within a closed space (room) or an outside arena, so that the concerned analyst can visualize the events in a 3 dimensional space.

5.2. Technical constraints –
1. While position based distances between individuals in the crime scene can be varied, the outside arena cannot be selected/ designed beyond the predefined options.
2. Though we intend to make the predefined options as varied as possible, yet inclusion of all possible scenarios cannot be guaranteed.
3. The particular emphasis of the software shall be on the position of the perpetrator, victim and bystander/s (if any) in the crime and on the different possible bloodstain patterns as extracted from the crime scene photograph that have been marked out by a pattern analyst.
4. The tool is not intelligent in itself, given the large scale variability and fragile nature of bloodstain patterns the tool shall help crime scene reconstruction with due input from an experienced investigator.

5. Over time the functionality of the tool shall be extended.

VI. Research – Relevant Work Done

As outlined, in our research work we intend to simulate the event of head hit at a crime scene. In this section, we would particularly want to highlight certain excerpts from the work that we have undertaken. Hypotheses that we have evidentially substantiated are,

Hypothesis 1: The quantity of blood that adheres to a hammer as also the surface area of the hammer to which blood adheres do largely control the pattern of the hammer transfer stain. But, a totally blood drenched hammer does not ensure a full body transfer impression of the hammer on a plain non absorbent surface [13].

Hypothesis 2: If the velocity and acceleration of a hit vary, depending on the area that was hit an individual can very well expect to see different transfer stain patterns [13].

Hypothesis 3: When a hammer undergoes free fall under gravity, we can expect to see changes /differences in bloodstain pattern owing to difference in fall height and weight of the hammer [13].

Hypothesis 4: Presence of a hammer or hammer like transfer stain/imprint does not imply that the hammer has been used as a murder weapon [14].

Hypothesis 5: Transfer stains produced by hammer in blood are markedly different from stains obtained when blood falls over a hammer [14].

Figure 15: Head Hit simulation done using a hollow coconut shell and hair wig.

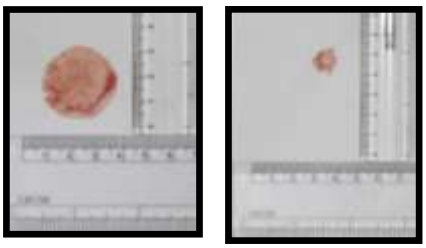
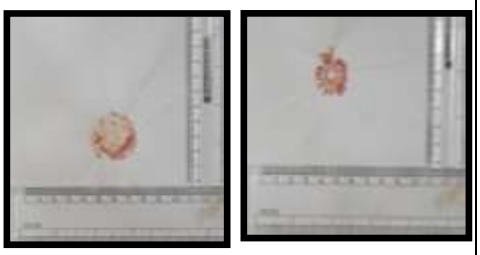
Hypothesis 6: Other blunt objects can also produce hammer or hammer like transfer stains or imprints [14].

Given that fabric texture, fabric absorption ability affect the transfer stain patterns, hence we have created all the stain patterns on a plain/smooth, non absorbent paper surface.

Figure 15 represents the experimental simulation that we created within the laboratory setting. A hollow coconut shell was used to mimic a human head. The height of the victim and the perpetrator was not considered because we were only interested in recording the transfer stains formed by hammer after around 10 head hits. At that point we weren't particularly interested in recording the different impact spatter patterns created as a result of back head hit with a hammer.

Table 1 represents the image of a ball peen hammer (row 1) and the different transfer stains that were produced with the same hammer by different physical mechanisms.

<table>
<tr><th colspan="4">Evidential Proof for each of the Hypothesis Generated</th></tr>
<tr><th>Hammer Type</th><th colspan="3">Hammer Specification</th></tr>
<tr><th></th><th>Front View</th><th>Side View</th><th>Isometric View</th></tr>
<tr><td>Ball Peen Hammer
Weight of head - 500gms
Weight of handle- 100gms
Material –
Head – Cast Iron
Handle -Wood</td><td>  </td><td>  </td><td>  </td></tr>
<tr><th colspan="4">Ball Peen Hammer Images Justifying Hypothesis 1</th></tr>
<tr><th></th><th colspan="2">After 10 head hits hammer was dropped from a height of 40 cms</th><th>After 10 head hits, hammer was dropped into a 30cc. blood pool, then picked up and dropped from a height of 40cms.</th></tr>
</table>

Evidential Proof For Hypothesis 1		
Ball Peen Hammer Images Justifying Hypothesis 2		
	After 10 head hits, bloody edge of hammer was placed on a plain , non-absorbent surface	**After 10 head hits, bloody edge of hammer was made to strike a plain, non-absorbent surface**
Evidential Proof For Hypothesis 2		
	Ball Peen Hammer Images Justifying Hypothesis 3	
	After 10 head hits, hammer was dropped into a 30cc. blood pool, then picked up and dropped from a height of 40cms.	**After 10 head hits, hammer was dropped into a 30cc. blood pool, then picked up and dropped from a height of 60cms.**
Evidential Proof For Hypothesis 3		
	Ball-Peen Hammer Image	
	After 10 head hits, hammer was dropped into a 30cc. blood pool, then picked up and dropped from a height of 40cms. Again, without 10 head hits, hammer was dropped into a 30 cc. blood pool, then picked up and dropped from a height of 40 cms – Similar stains were obtained	

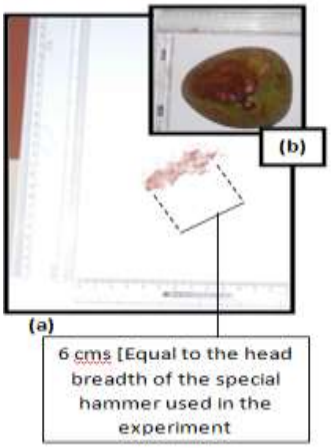
<table>
<tr><td>Evidential Proof For Hypothesis 4</td><td colspan="3"> 
From this hammer imprint it cannot be deduced whether the hammer has been used for head hit or not</td></tr>
<tr><td></td><td colspan="3">Ball Peen Hammer Transfer Stain Justifying Hypothesis 5</td></tr>
<tr><td></td><td>Transfer Stain formed when a hammer is left for 20 mins in a pool of blood(30cc) and then placed on a plain, non absorbent substance</td><td>Transfer Stain formed when 20cc. blood is allowed to drip on hammer and is then is left for 20 mins ,then placed on a plain, non- absorbent surface</td><td>Imprint formed in a 20 cc. blood pool, when a hammer is left in the blood pool and the pool is subsequently allowed to dry- 1.5 days</td></tr>
<tr><td>Evidential Proof for Hypothesis 5</td><td>  </td><td>  </td><td>  </td></tr>
<tr><td></td><td colspan="3">Ball Peen Hammer Transfer Stain Justifying Hypothesis 6</td></tr>
<tr><td></td><td>Special Hammer Front view</td><td colspan="2">Special Hammer Face transfer stain re-created after 10 head hits with a hollow coconut shell</td></tr>
<tr><td>Evidential Proof for Hypothesis 6</td><td>6 cms. is the head length of thehammer
  </td><td colspan="2"> 
(b)
(a)
6 cms [Equal to the head breadth of the special hammer used in the experiment</td></tr>
</table>

Table 1: Transfer Stain Images from the work undertaken [13][14]

We could ideally use semi-supervised learning techniques for analysis and interpretation of hammer transfer stains. But owing to the large variability of the different types of available hammers, the variability in the stain pattern owing to the texture, absorption ability of surface and the fact that even other blunt objects can create hammer like transfer stain patterns, it stands integral to study circumstantial evidence such as wound patterns, absence/presence of objects at the primary crime scene, other cast off patterns on the walls and ceilings in order to properly interpret the weapon transfer stain at a crime scene. Velocity of hit, fall height, mass, dimension of hammer, angle of inclination, height of fall , amount of blood on the hammer , hardness of target surface have significant effect on the transfer stain pattern formed. Therefore to build a semi-supervised tool to probabilistically interpret transfer stain patterns, the greatest challenge lies in creating a database that has large variation and has a balanced representation from each class considered.

Figure 16: After 10 head hits, claw hammer fell under the effect of gravity from a height of 40 cms onto a plain/smooth and non-absorbent paper surface, and the hammer transfer stain was superimposed by a half bloody shoeprint

Again, given the fragile nature of bloodstain patterns at a crime scene, analysts often come across superimposed stains that are difficult to interpret. Hence given the vast probability of possible superimposed stains it's indeed challenging to build software that could segregate out the weapon transfer stain from the complex superimposed stain(refer Figure 16).

VII. Future Scope of the Work

The work could be extended by attempting at identifying probable features, qualitative as also quantitative that could be adequately used for a software system to make probabilistic predictions on the possible mechanism that could have created a particular transfer stain based on the principles of semi-supervised learning. However, given the large number of superimposed stains that are spotted at a crime scene (owing to the fragile nature of the bloodstain pattern), the difference in the way different surfaces react to a particular stain type based on surface texture, permeability, absorption ability etc., development of an extensive as also authentic database seems to be the greatest challenge in creating such a tool that could add value to crime scene reconstruction process in the real world, where each crime scene is unique in itself .

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