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Editor's Note

After the success of the inaugural edition in 2014/5, we are proud and pleased to present the second edition of the *Bauhinia*. Once again, it showcases interesting and impressive work produced by our students, as a result of the Needham Research Institute's Scholars' Retreat in Cambridge, the ISF Academy Shuyuan and IB DP Extended Essays. This compilation of academic essays is a testament to our students' tireless work ethic, intellectual curiosity and inspired engagement across a wide range of subject areas and in a bilingual setting.

The *Bauhinia* aims to be a literary celebration of all that the ISF Academy stands for, as encompassed by the *Eight Virtues + One*. It provides a unique opportunity for our students to pursue their thirst for wisdom (*zhi*) and exhibit their commitment (*zhong*) to researching their chosen topic; they can make informed, balanced judgements (*ping*) in order to produce their own work to the highest standard, of which they can be proud of (*yi*), whilst being respectful (*xiao*) and mindful (*ren*) of other writers and works on their chosen topic and aiming to create a common ground (*li*); and they can passionately immerse themselves (*ai*) in their topic area, as well as share their research with others, creating harmony (*he*) in their work and in their field of research.

We hope that this edition fittingly builds upon its predecessor's legacy and our academic journal continues to flourish, exhibiting the maturation of the ISF Academy and its outstanding young scholars.

In true ISF bilingual and inter-cultural fashion, I would like to leave you with two final thoughts that I feel characterise *Bauhinia*'s humble place in the academic world and reflect its modest contribution to life-long learning:

Do not train children to learning by force and harshness, but direct them to it by what amuses their minds, so that you may be better able to discover with accuracy the peculiar bent of the genius of each.
Plato

You cannot open a book without learning something.
Wang Pizhi (Song Dynasty)

Anastasia Christou

繼上年度《紫荊花》雜誌的順利出版，我們欣慰地將新的一期刊物奉獻給讀者。本期刊載了一些優秀的學術論文，它們是弘立書院同學學習成果又一次很好的檢閱。無論是他們在劍橋大學李約瑟研究所內進行的研究，還是他們通過書院課程研讀、拓展論文和知識論論文的寫作，這些來自不同學術領域和反映了不同興趣的論文的完成，顯示出我們同學巨大的學術好奇和他們兢兢業業的學術追求。同時，它們也彰顯出我們學生在研究過程中雙語操作的質量。

《紫荊花》雜誌是弘立書院「八德一智」辦學方針在學術領域裡的一個有力見證。總結說來，它體現了同學們強烈的學習渴求（智），和他們持之以恆的學術努力（忠）。他們在選題過程中通過廣泛收集材料，進行公平、尊重的研究對話（平，義），進而形成自己的有價值的結論（仁，禮）。在學習和研究的過程中，他們實踐了團隊的合作，體驗到追求真理的巨大樂趣（愛，和）。總之，這是同學學術、理念和精神成長的果實。

在上一期《紫荊花》成績的基礎上，我希望本期刊物以至未來陸續的出版，能夠不斷後浪推前浪，更上一層樓，成為催化青年學者成熟的搖籃。

在弘立書院雙語、雙文化的旗幟下，我將和大家分享兩句名言，作為《紫荊花》雜誌在浩瀚學術海洋中對自己謙恭的定位，以及對學生終生學習的一點警策。

不要以威勢或嚴厲訓練孩子的學習，讓他們由感到快樂的事物引導他們吧，這樣你就能精確地發現每一位天才獨特的才華。 — 柏拉圖

開卷有益。 — 王闢之（宋）

唐朝西域的服飾紋案對中國絲織品紋案之影響

張藹文

中國上下五千年的文化離不開人民基本的衣、食、住、行等生活條件。絲織品在中國古代文明中佔有十分重要的地位。中國對養蠶技術的記載可追溯到上古黃帝與嫘祖的傳說。《繹史．黃帝紀》載：「黃帝斬蚩尤，蠶神獻絲，稱織維之功」；《史記．五帝本紀》載，黃帝「時播百穀草木，淳化鳥獸蟲蛾」。蠶桑絲綢的發明權歸於黃帝（朱新予，3）。蠶絲作為中華文明的一個重要的代表，歷代一直是對外通商的重要物品。 絲織品的紋案不僅體現了當朝流行文化，也呈現了當時的社會環境、歷史、風俗等。唐朝被公認為是中國古代最繁華最富有的朝代，對外通商十分頻繁，所以在唐代的絲織品中最能體現唐朝與西域的文化交流之結果。中西交流雖不止侷限在絲織品中，但是從一種高貴的奢侈品的角度去看兩種文化的交流樣貌，可以了解到西域的藝術文化到底對古代中國文化發展產生了什麼影響。

從漢朝開始，「絲綢之路」已經聞名。漢朝的張騫二次出使西域，使絲綢之路變得暢通與繁華。「由於張騫開拓了長期被匈奴阻塞的東西交通，溝通了被中斷的東西方經濟、文化交流，使漢族和西北邊疆各族，中國人民和亞洲、歐洲各國人民的友好關係進入一個嶄新的階段」（楊建新，13）。絲綢之路分為陸路絲綢之路、海上絲綢之路等。陸路絲綢之路分為「西域道」、「吐蕃道」、「永昌道」。本文只專注陸路絲綢之路的「西域道」貿易對唐朝絲織品紋案之影響。「西域道」在唐朝時期「十分繁忙，不僅在史料中有記載，而且在磚刻上、唐三彩中，特別是在織錦紋樣上，都出現了以各種馱著絲綢的駱駝及牽駝人為內容的圖案」（朱新予，173）。繁榮的西域道是唐朝時期絲綢之路對外通商最頻繁的通道。它一直向西延伸到伊斯坦布爾，向南到達仰光等，途中經過西部的敦煌、疏勒（今喀什）等地。踏出國境就會到達大宛（今烏茲別克斯坦費爾干納）、大食（即阿拉伯帝國）、波斯和拂菻（即拜占庭帝國）等地，再向西就會到達地中海沿岸的富有國家。而西方的文化就是絲綢之路通暢後慢慢進入中原並影響著那裡的文化。

絲綢是古代中國最重要的紡織品之一，是皇室與商賈的寵愛。唐朝的「絲綢紡織手工業，更發達迅速，全國各地，無不各有特別名產，而以川蜀、江南及河南、河北三大產區成就格外著名。蜀中錦綵（部分指印花），吳越異樣紋綾紗羅，河南北紗綾，都為國內珍品，除每年入貢長安，還以商品方式在全國市場上大量行銷，並由西北陸路及廣州、明州、信州、揚州海路遠輸海外」（沈從文，306）。珍貴的絲織品製作工藝複雜並且種類繁複，「當時在繒或帛的總稱下，就有綺、縑、綈、紬、縵、縠、素、練、綾、絹、縠，以及紗、羅、緞等花色品種」（楊建新，49）。雖然絲綢分為如此多的品種類型，但是它們都擁有一些相同的品質。用蠶絲製作的絲綢纖維長、韌性大、彈性好、纖度細，且具有空隙，既透氣又吸濕，在加工的過程中易於染色 。正因為這些誘人又出色的特點，才會讓絲綢成為商人與皇家貴族的寵愛。在唐朝，工匠們更臻完善成熟的染纈技術給這些絲帛錦上添花。他們使用以及完善的染纈技術包括：絞纈（絞染）、臘纈、夾纈（圖案規則對稱）、鹼劑印花、泥金銀凸版印花，給本身就精緻的絲綢增光添色，讓在西域的顧客和貴族們再也找不到不偏愛絲綢的理由，同時西域人民的喜好也慢慢影響了唐朝中原地區的絲綢紋案。

唐朝的服裝與其他朝代的服裝在款式上以及紋案上都有大不同。「隨著國家的統一，隋唐朝廷都曾參照前朝舊制，改革與服制度，規定天子、百官的官服用顏色來區分等級，用花紋表示官階。隋代朝服尚赤，戎服尚黃，常服雜色。唐代以柘黃色為最高貴，紅紫、藍綠、黑褐等而下之，白色則沒有地位」（沈從文，王矜，76）。這只是隋唐代官服的分級方式，可見服裝與服飾的顏色搭配不僅表現一個人的財富，也體現其權力地位。所以服裝樣式與其用料、顏色、質地、剪裁在上流社會有舉足輕重的地位。隨著歷史

的變遷，改變的不僅僅只有官服制度，還有製作絲綢的方式。從初唐開始，絲綢的製作方法從一直以來的經錦製作方法，變成了緯錦製作方法。這是初唐開始從西方傳來的製作方法，因其頂尖的質量以及突出的樣式一直沿用至今，緯錦較於經錦的優勝點在於操作簡單方便，結構簡潔，能夠減少勞工成本。用經錦製作方法生產的絲綢成品沒有緯錦製作方法的成品精緻細膩，水平相差甚遠，所以此後民間只流行用緯錦的製作方法，經錦織製被慢慢放棄。還有一項在唐朝有突破的技術就是染纈技術。正如之前所說，唐朝的織製與染錦技術到了登封造極的地步，把絲綢的特性發揮到極致。

為了能夠更完整地了解唐代外來文化以及自身文化的發展，從絲綢身上去尋找線索最好不過。這種豪華的奢侈品花樣多變，從西域進入中國的文化必將會影響到絲織品上的紋樣。因為唐代的絲織品全是手工製作，所以多變的紋樣成為了一種美麗的象徵。絲綢上有不同的花紋、紋樣，不同的花紋、紋樣有不同的紋樣組織形式，而這些不同種類的花紋圖樣便能分出富貴貧賤，成為階層等級分化的象徵。

從花紋、紋樣上來看，絲織品的花紋分四種：植物花紋、宗教花紋、動物花紋、幾何花紋。植物花紋包括衆所周知的各類花卉，比如牡丹、芍藥、蓮花等，是中國藝術中比較傳統而且常見的花紋樣式。宗教花紋以道教、佛教紋飾為主。絲織品上的動物花紋有鹿、山羊、馬和一些神話的動物。而幾何花紋明顯就是平常生活中常見的幾何圖形，如方形、 圓形、三角形等圖案，那些簡單但素雅的圖案也得到了很多工匠的喜愛。這些花紋的組織形式有六種：聯珠團窠式、團花式、對稱式、自由散點式、唐草紋式、幾何形式。而唐朝的絲綢圖案有幾種特色，包括有圖案的對稱以及有曲線線條的美麗，體現出明顯的封建倫理道德觀念，且雍容大度蓬勃向上，盡顯唐朝貴族的風度與氣勢。

通過絲綢之路進入中國的不僅僅只有貨品，還有商賈從西域帶來的文化。「大略地說，此路東起漢唐時的都城長安，經河西走廊而到敦煌。由敦煌起可分南北兩路。南路從敦煌經樓蘭、于闐、莎車等地，越蔥嶺到大月氏（阿姆河中部）、安息（波斯，今伊朗），再往西可達條支（伊拉克）、大秦（羅馬帝國，今地中海沿岸）。北路從敦煌到交河、龜茲、疏勒，越蔥嶺到大宛（烏茲別克斯坦費爾幹納），再往西經安息而達大秦」（趙豐，27）。從絲綢之路進入中國的西域文化是從這些沿路的國家中來的，包括他們入口的動物、花瓶、衣服等，而他們在中國通商時帶來的宗教、文化等對中國文化的影響也很深遠，而從絲織品的紋樣上能夠看到中國對其他西域文化的逐漸接納與融合。

圖1　孔雀刺繡花卉紋錦（沈從文）

首先，在唐朝絲織品紋樣中最著名的唐草紋明顯地體現出唐朝與埃及、羅馬的文化交流。這種紋樣在初唐時就出現。這個花紋的原型是發軔於埃及、羅馬的忍冬花圖案。忍冬花即金盞花，這朵花的花瓣有著十分美麗而且自然的弧形，而古埃及人就已經能很好捕捉忍冬花的曲線。唐朝的工匠看到這美麗的忍冬花紋，就將其變為當朝盛行一時的唐草紋，與忍冬花十分相似，在很多布料以及絲織品上都能找到它的蹤跡。在巴黎吉眉美術館藏的唐朝纏枝朱雀錦上織有葡萄、蓮花等紋案，十分清晰生動，當然也包括唐朝盛行的唐草紋。這種組合的紋案非常圓潤豐滿，給人豐

圖2　唐朝花樹對鹿紋 （沈從文）

饒圓滿的感覺。除了這件絲錦，還有很多其他的錦帛例如唐朝「花樹對鹿紋綾」（圖3），其上清晰可見的唐草花紋是很好的中西文化交流的例證。從歐洲來的太陽神赫裡奧斯（Helios）也曾出現在唐代的絲綢上，「有一件紅地簇四云珠日神錦是西北內層聯珠合成圈，圈間用鋪獸和小花相連，圈外是卷雲紋和中文『吉』字，圈內是太陽神赫裡奧斯」（陳永昊，140），當時的太陽神赫裡奧斯已經經過了很多文化的浸染，變得與原型不同，但是還能夠辨認出其身份。

西域對中國的另一個重大影響就是宗教文化。中國本土的主要教派為道教。但是從西域以及外國傳來的教派中，中國特別被印度教與佛教影響。比如印度教裡的提婆（Deva）曾出現在出土的絲織品中，「新疆吐魯番出土的《高昌條列出臧錢文數殘奏》中多次提到『提婆錦』的名稱，應是產於內地並具有『提婆』圖案的織錦」（趙豐，133）。佛教中的大象的象徵，也頻繁地出現在一些絲織品上，例如在日本正倉院藏的唐朝「羊樹屏風和象樹屏風」上，可以看到非中國本土的大象和猴子形象。又比如說寶相花圖案，一個被西域文化影響產生的植物圖案，在佛教藝術中，寶相花是吉祥且豐滿圓潤之佛象，與寶蓮花有很多相似之處，具有如意美好的意義。

圖3　新疆出土寶相花紋錦 （沈從文）

唐初從波斯進口的藝術品中的「聯珠團窠紋」也證明了西域藝術文化對中國唐朝的絲織品紋樣的影響。這種紋案組合在西域十分常見，但是在出土的唐以前的絲織品上鮮有蹤跡。通常聯珠團窠紋分為小團窠聯珠和大窠唐草聯珠，在大窠唐草聯珠中又分為粟特錦和新月紋錦。「粟特」是一個中亞古代的民族，以商業買賣為主，粟特錦就是以他們命名的。粟特錦如以圖案來區分的話會有兩大類，第一種是使用了花卉或者變相聯珠紋等來組織成大窠聯珠，「中間以動物紋作主題，窠外則是較為稚拙的十樣花，窠形尺度一般較大」；第二種「則沒有團窠，但其他的技術象徵基本相同。」在日本法隆寺藏的唐朝「四騎士」狩

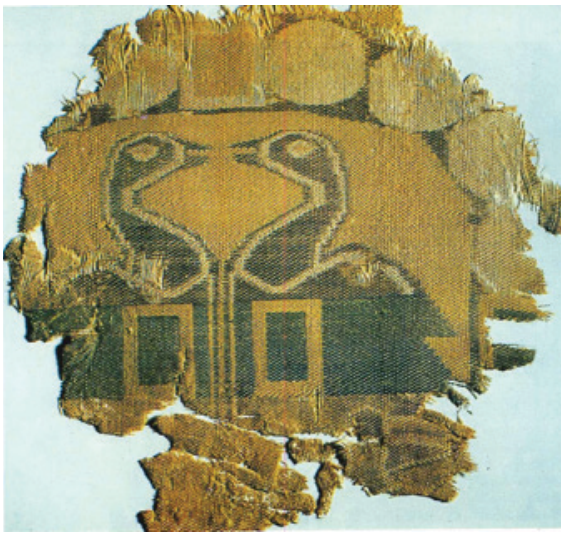

圖4　大窠聯珠紋 （沈從文）

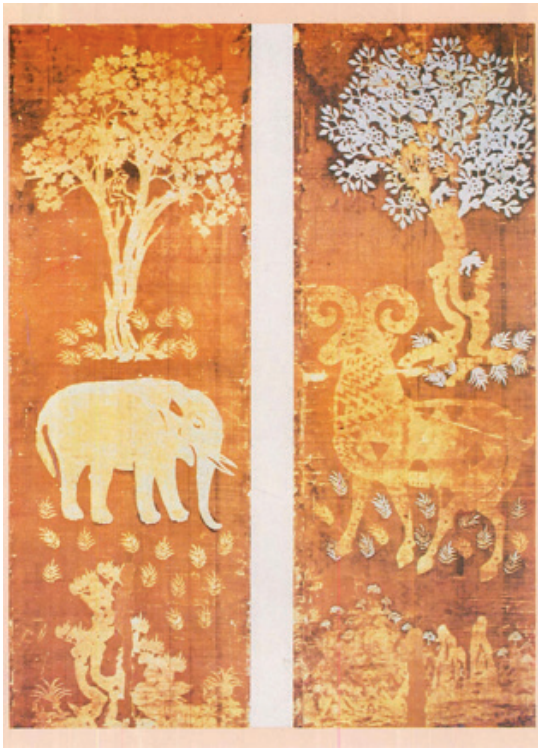

圖5　羊樹屏風與象樹屏風（沈從文）

獵文錦就是採用了這類的圖案，其團窠尺度比較大，但中間明顯地以動物紋為主體，以顯示出「狩獵」的主體。

最後，因從外國進口入中國的珍禽異獸數不勝數，唐朝絲織品上出現了許多不是中國本土的動物，這也證明了中國通過絲綢之路與西域交流的範圍之廣。其中最受中國人喜愛的是從南亞來的孔雀和大象，從印度和波斯來的獅子、牡馬鹿、野山羊，從西亞來的駱駝等。它們都成為了絲織品上常見的圖案，唐代製作的絲織品也慢慢地有了異域風情。拿獅子來說，印度和波斯的獅子對中國產生了影響，漢代宮廷已有獅子舞，但獅子形象遲至北朝才出現在絲綢上，到唐宋時達到頂峰。而在印度，大象是佛的化身，也被人民追捧，由於唐代佛教盛行，因而唐代絲錦上也頻頻出現大象的身影。像在日本正倉院藏的捻線綢蠟纈屏風上出現的大象與山羊可以體現出非中國的動物形象通過商業途徑而傳入中國的痕跡。當然還有從南亞來的孔雀。雖然古代中國不是孔雀的故鄉，但是在唐朝的絲綢文錦上有孔雀的紋案出現，代表了中國與亞洲各地的交流十分頻繁。孔雀也被譽為「神鳥」，以它優美婀娜的身姿和色彩繽紛的羽毛，被中國的皇室貴族們奉為高貴儒雅的象徵。

綜上所述，唐朝時期的西域文化多姿多彩，而透過唐代的絲織品，我們能清楚看出的西域文化對中國文化（尤其是中原文化）也帶來了不可磨滅的影響。這種影響體現在紋案組織、絲綢製作、絲綢浸染，或是紋案設計等眾多方面。而這些與本地風格不同絲織產品能夠在唐朝流行，受到貴族追捧，與當時的社會風氣也是密不可分的。唐朝是一個開放而且多元化的朝代，當時婦女的著裝艷麗，對西域傳入的風俗文化，人們不僅不加排斥，反而將其捧成了流行時尚，將其變為綾羅綢緞上的紋飾，使其得以流傳至今。從這一切都能看出，唐代是中國歷史上一個不同尋常的開放並富於創意的朝代。

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To What Extent Does Anti-Persian Sentiment Colour Herodotus' Description of Cambyses II?

Karie Kam

Herodotus was a Greek historian and is known as the founding father of history in western literature. His *Histories* is an investigation of the Graeco-Persian War and includes a great quantity of detail regarding significant individuals, including Cambyses II, the mad Persian king. This essay will examine and discuss the way Herodotus portrays Cambyses II and how his bias, as a result of the war with the Persians, influences his writing about the Persian king. Herodotus' anti-Persian sentiment is clear in his account of Cambyses when describing his sacrilegious conduct towards other cultures and customs; his poor judgement and leadership of his own subjects; and his behavior that may be considered "mad" in general.

First and foremost, Cambyses II is depicted as showing great disrespect towards the traditions of different cultures, including his own. In 3.16.4, Cambyses is described to have opened the tomb of Amasis and mutilated then burned his body; thus showing the first stark example of his sacrilegious behavior as he "commanded the doing of a thing contrary to the custom of both [Persian and Egyptian] peoples." Later in Herodotus' narrative, Cambyses then wounds and eventually kills the Egyptians' sacred Apis bull, stating that "when the priests led Apis in, Cambyses—for he was well-nigh mad—drew his dagger and made to stab the calf in the belly, but smote the thigh; then laughing" (3.29.1). This section negatively characterises Cambyses as a self-centered, perhaps even mentally deranged king.

The story of Cambyses, as told by the anti-Persian Egyptians, is known to end with him paying for his sacrilegious behavior towards Egyptian customs with his own sanity. Herodotus writes that "by reason of this wrongful deed, as the Egyptians say, Cambyses' former want of sense turned straightway to madness" (3.30.1). However, we may look further into this, and see that Herodotus most likely gathered this information from native sources, namely the Egyptians themselves, who had strong opinions against the Persians. There is a "thread of undying hostility in Egypt to the Persians" (Dillery, 397) because of Cambyses' conquest of Egypt and his actions mentioned previously. Thus, by frequently citing the view of the Egyptians, Herodotus' characterisation of Cambyses automatically becomes negative, emphasising his disrespectful and sacrilegious behavior.

Herodotus' anti-Persian sentiment is also shown through his description of Cambyses II's inadequate leadership of Persia. One of the most prominent accounts in the descriptions of Cambyses is about his expedition against the Ethiopian king, while "being not in his right mind but mad" (3.25.2). As Cambyses gives orders to march upon Ethopia, he does not "give any command for any provision of food nor considers that he was about to lead his army to the ends of the earth; and, he marched at once… taking with him all his land army" (3.25.2). His subjects later resort to cannibalism in order to survive and only when the situation becomes this extreme does Cambyses finally realize his mistake and turns back. This account of Cambyses' poor leadership of his army sheds a negative light on his character, showing not only that he was impulsive and rash in making military decisions, but also stubborn up to the point where his subjects are forced to do terrible things just to survive.

"Cambyses' own involvement in the campaign and his hasty decision to attack the Ethiopians is attributed to his madness, first mentioned at this point in the narrative" (Dillery 394). This descriptive account of Cambyses' expedition against Ethiopia, along with accounts of the outrageous actions Cambyses committed later on, support a notion that Herodotus' purpose was to construct a vivid image of Cambyses' madness. He uses extreme aspects or consequences of Cambyses' decisions to paint him in a negative light, showing bias against the Persian king.

Finally, Cambyses II is generally characterised as mad, and Herodotus provides multiple justifications for his claim.

Herodotus often points out that Cambyses was in a state of madness when carrying out his outrageous actions. The murder of the Apis bull, as mentioned previously, is one of these instances: "we have seen Cambyses' madness as an explanation before, and the crime against the Apis serves to launch the theme in earnest" (Dillery 395). Cambyses is also shown to be insecure and incredibly jealous of his brother, who was more capable than him in strength. His insecurity even caused him to go to the extent of committing fratricide, then murdering his sister and wife when she tried to question his choices. By stating these to be "mad acts to his own household" (3.33.1), Herodotus provides further evidence for Cambyses' madness. After some accounts of Cambyses' outrageous actions, such as when he destroys his allies' sacred temples, Herodotus then says, "I hold it then in every way proved that Cambyses was very mad; else he would never have set himself to deride [his own] religion and custom" (3.38.1). This suggests that Herodotus believed a culture's customs were extremely important, and that by his sacrilegious behavior, Cambyses "falls outside the norms of civilised behavior" (Selden 56).

There is also another justification for Cambyses' actions that is given by Herodotus, namely that the king is said by some to have had epilepsy from birth, and that it is "no unlikely thing then that when his body was grievously afflicted, his mind too should be diseased" (3.33.2). We may therefore conclude from all Herodotus' justifications and evidence for Cambyses' madness mentioned above, that he did truly believe Cambyses was mad. For this reason, it may be argued that Herodotus was justified in negatively portraying Cambyses, though his Greek bias in general is still prevalent throughout his work and must always be borne in mind.

To conclude, Herodotus' bias colours his account of the mad Cambyses II to a great extent, as he paints him in an extremely negative light. Herodotus may be justified to some extent, however, when focusing on Cambyses' negative actions, because he provides evidence to support the claim that Cambyses had a mental illness. Herodotus' writing later influenced other historians' accounts of Cambyses' deeds, causing the Persian king's unfavourable reputation to be passed down through the ages. Overall, having analysed this text, it may be concluded from this section of Herodotus' *Histories* that Cambyses, although a prominent figure in Persian history, was negatively portrayed in this way because of Herodotus' Greek bias against Persia.

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論兩種產生知識的方法：被動的觀察或積極的實驗

譚天傑

從看雲識天氣到徒步征服世界最高峰，自人類歷史的發端，觀察與實驗便貫穿於人類求知的各個領域。普遍的看法是，觀察和實驗是幫助人們獲得有關外部世界知識的不二法門。這篇論文將主要探討被動的觀察與積極的實驗在不同的知識領域中如何促進知識的產生，以及這兩種手段的局限性，並且會探討在多大程度上，人類知識能通過二者之外的其他手段產生。

自然科學也許是運用積極實驗最多的學科了。實驗被用來檢驗某種假設或驗證某種已知理論（知識論指南,37）。在物理課上，有一次我做了一個有關彈簧常數的實驗：顧名思義，彈簧常數只與彈簧自身的材料有關，可這是在假定溫度為定量的情況下，通過許多的實驗結果所做的論斷。我假設如果溫度由定量轉為變量，彈簧常數也會相應地改變。於是，我使用積極的實驗來驗證我的假設，因為規範的實驗（通過足夠多的試驗次數以及對定量的良好控制，來減少可能的觀察者期望效應）可以在相當大程度上確保實驗結果的可靠（Gauch 133）。如此的積極實驗合乎公認的科學方法：通過收集可觀察、可經驗（empirical）與可量度的證據（Cadin 149），將實驗證據與相關理論相比照分析，從而創造出新的知識。被動的觀察在自然科學裏亦十分有用：在天文學中，因為天體的不可控，要確認它們的運行軌跡和運動性質，往往只能通過用電磁波、紅外線等手段觀察（*Journey to the Edge of the Universe*）。雖說此類觀察手段仍受到器材精確度的侷限，但因為觀察這一行為並不可能對天體本身的運行造成任何影響，使它在很大程度上向人們提供了相對可靠的數據，並且創造出有關宇宙天體的新的知識。

可是，不難看出，在我的彈簧實驗裏作為認知方法的推理，融入到了實驗與觀察之中，可作為生產知識的一個途徑。在通過足夠多的試驗之後，我需要通過歸納、推理，根據實驗結果推出能確認或是推翻我的假設的一般性結論。同樣地，推理也被用於許多其他自然科學領域的實驗。比如說，德國科學家亨利希・赫茲於1888年建立了一個電路，無意中電路一角蹦出的火星引起了房間另一邊另一顆火星的出現。在這樣一個純粹通過觀察所得出的現象之上，赫茲通過推理得出了電磁波的存在 (*Heinrich Hertz's Wireless Experiment*）。而在這之前，他當然也做了許多其他實驗以驗證這樣的現象並非巧合。再回到我的彈簧實驗，具體來說，如果五次試驗中彈簧的溫度與彈簧常數符合假定的規律，那是否就意味著能通過推理來確認我的假設呢？如果一百次、兩百次試驗都符合規律，是否就能意味著推理有著更堅實的基礎呢？所以說，在自然科學領域最重要的三種產生知識的手段—實驗、觀察與推理有著緊密的聯繫，而且經常是彼此分不開的。

人文科學是一門應用自然科學的方法來檢驗人文領域裡假說的可靠性及有效性的學科（知識論指南39），自然也會對以上所列的三種產生知識的方法有廣泛的運用。比如說我希望通過我的某篇論文探討微觀經濟學的一個概念—價格歧視在一個零售市場中的運用。可是，據我所知，在此之前並沒有任何以這個零售市場為研究對象的研究。為要達到我的目的，我可以通過兩種知識手段，觀察與實驗中的某一種來獲取與價格歧視行為相關的信息。比如說，我可以通過被動的觀察，記錄商家的定價行為，從而確定它是否符合價格歧視的條件。我也可以選擇實驗的方法，通過假扮不同身份的顧客，購買不同數量的同一商品，來達到我的研究目的。只是這樣的實驗並不符合舊的規定。可是，在這樣的背景下，實驗與觀察的局限性可能會導致知識產生的不可靠。因為跟很多其他人文學科的研究一樣，價格歧視在這個零售市場的運用並不具有不允許個別例外現象存在的嚴格定律。換句話說，我所觀察到的價格歧視行為也許只是在某個特定時段在個別商家身上發生的事情。因此，我需要通過問卷統計、訪談與資料分析等一系列活動來得到價格歧視被應用的程度，從而提高結論的可靠性。

在另一方面，人類遠遠不只用觀察與實驗兩種方法去獲取知識。在幾個知識領域中，比如說數學，觀

察與實驗並不是主要的產生知識的手段。比如說，在去年的數學研究中我第一次接觸到了『虛數』的概念。這樣一個負數的平方根，推翻了我之前所理解的數字的概念。在中學的數學課上，我被告知任何一個數字，包括負數，都可以與數軸上的某點相對應，可是數軸卻無法被用來表示虛數，而且虛數作為一個數字，並不能代表任何數量。這使我產生了重大的迷惑。後來，導師啓發我虛數能對應平面的縱軸，與對應平面橫軸（即是我所理解的數軸）的實數同樣真實。在這樣獲取知識的過程中，觀察與實驗起不到任何作用，也沒產生效果。因為虛數在真實世界中不存在，自然也不可能通過實驗或觀察來加以理解。我認為，作為認知方法之一的想象在這裏起到了很大作用。只有通過想象虛數為合理的，可表示的『數字』，人們方能理解以縱軸表示虛數，並將虛數與實數同樣看待的理由。在這過程中，我使用想象將我所不能理解的虛數帶入到了我的知識範圍之內，並且假設它是一個符合我所能理解的概念（實數）。想象對於理解虛數的重要性，恐怕也能通過虛數的英文名—想象數（imaginary number）略窺一斑了。

當然，我並不是說觀察與實驗在數學中毫無用處。伽利略曾說過：『大自然這本書是用數學來寫的』。的確，許多數學定理來自於對大自然觀察時所受到的啓發。最著名的例子要數通過觀察大自然中的形狀，例如向日葵及鸚鵡螺，所得出的黃金比例 — 0.618 (袁小明 72)。而黃金比例在大自然裏許多其他的物體中亦得到印證（袁小明 73）。而積極的實驗對數學亦有重大貢獻。例如古希臘數學家使用『窮舉法』，通過不斷嘗試構造盡量多邊的圖形，以獲得圓周率的近似值（袁小明 95）。

總之，本論文在一定程度上不同意有關人類只有通過觀察和實驗才能獲得知識的說法。經過以上的探討，我們可以得出結論：被動的觀察或者積極的實驗的確可以在不同知識領域中幫助人類生產知識，但它們亦有局限。而且，觀察與實驗並不是生產知識的唯一途徑。其他認知手段與認知方法，如推理與想像，也能幫助人類有效地生產知識。

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Forensic Science and Stability of Society: From the Song Dynasty

Pokman Chan

Forensic science: the use of scientific method to process and resolve cases related to the interest of judiciary systems. The most common practice of forensic science would be crime scene investigation. From the collection of evidence of fingerprints for the analysis of blood and the human body, forensic scientists can indirectly support the prosecution or defense in criminal and civil investigations. The work of a forensic scientist, however, can directly affect the fate of criminal; to the level of life and death in some countries. Despite the serious nature of their work, they still make a positive impact on society. As a part of the judiciary system, forensic science contributes to maintaining and protecting the stability of a society, alongside law enforcement.

The earliest evidence of forensic work can be traced back to the Era of Warring States (475 BC ~ 221BC), as China has the earliest record of having an awareness of forensic work after wrongdoings (Jia, 45). Judges and coroners from the sub-prefectures were deputed for each case and these officials would oversee whole investigations. However, some of the observations from the coroners and judges were later proven with scientific justification and were adopted by some modern forensic scientists. Forensic science has helped to shape ancient Chinese culture, as it was merged into the legal system, much like today. Through analyzing how the ancient Chinese forensic system was established, evidence of its contribution to and significant impact on the entire Chinese society can be discovered.

An important figure of ancient Chinese forensic science is Song Ci. Song Ci, born in 1186AD during the Southern Song Dynasty, who served as the presiding judge in the Chinese high court for many of years. Song Ci believed that forensic science could help to discourage unwanted activities in society and was a keystone in the peacekeeping of a society. Known as the Founding Father of Forensic Science in China, Song Ci established the fundamentals of forensic science through his book, *Xi Yuan Lu* (*Washing Away of Wrongs*). In most cases, forensic science would be the last resort for the innocent; hence the reason Song Ci named his book, *The Washing Away of Wrongs*.

The *Xi Yuan Lu* was written in around 1247 as a handbook for other judges at the time. The book is divided into five fascicules, with a total of fifty-three chapters. The *Xi Yuan Lu* begins with a detailed list of laws and regulations judges must follow and the punishments if they fail to do so. The second volume illustrates how autopsy should be undertaken and executed. The last three volumes describe and explain how a judge should determine between the various causes of death through physical features on the corpse and treatments of certain injuries. As a judge himself, Song Ci included his own experience with many other historical cases in his book. With the aim of introducing forensic science to be used by judges, Song Ci focused heavily in his book on precise technical procedures and methods. As the earliest existing systematic forensic work, this book unravels how forensic work posed an importance to ancient Chinese society and its contribution to social stability.

The laws and regulations of a judge can be found in the first volume and at the beginning of the book, therefore showing the significance Song Ci believed it had. The imperial decree for judges and coroners was strict in the Song Dynasty. Corruption was a serious issue at the time, as people with power and money would sometimes reduce, or even avoid, their punishment. Common people without this power or money were often accused of crimes they had not committed. False accusations led to the death of innocent people. As a counter to this phenomenon, strict

laws have been established. The crime of judges and coroners accepting bribes was also a serious one during the Song Dynasty. As mentioned in the *Xi Yuan Lu*, officials who accepted bribes worth twenty lengths of silk could be found guilty of breaking regulations and would be sentenced to the penalty of strangulation. Song Ci warned that all deputed officials must not have any personal involvement in their case. This was to avoid any prejudice, which might have led to an unfair judgment in the result of the investigation. Under his recommendations and warnings, civilians would be able to obtain justice. People would believe in the results of the investigation carried out by coroners and judges, where criminals would be caught and brought to justice. They would receive the right punishment, with the aid of forensic science.

Another common cause of injustice in Song Ci's time was the malpractice of false accusations. In the *Song Xing Tong (Compendium of Song Laws)*, it was recorded that people must not falsely accuse a third party through claiming that other causes were involved in the death. People who committed this crime would be found guilty of false accusation, would face strict trials and be punished with one hundred blows from a heavy rod. *Xi Yuan Lu* even records the strange situation wherein one would poison or kill themselves to accuse others, even if it meant their own death. To prevent being misled, judges and coroners needed to clearly determine the cause and time of death. Forensic science would be used to discover these malpractices, and helped defend the innocent. This was to ensure that judges and coroners remained neutral throughout the investigation. The serious consequences were a warning to judges and coroners about the independent and neutral status of their work. After all, social stability cannot be established when the civilians of a prefecture do not have trust in their officials. Song Ci believed that the trust between officials and civilians was the most important part of a judge's job, and therefore recommended that judges and coroners follow a few tips to gain the trust of the civilians.

A good example of such a tip is to follow the special practice of ancient Chinese forensic science: public examinations of the corpse. One practice Song Ci singled out was that the examination of the corpse should be performed in public, even when the victim of the crime was a servant. There are clear instructions for judges on how to carry out these public examinations:

> "If the victim was a serving girl in the family of a rich man, first measure her position relative to the surroundings, then have the body carried out to the street. Then examine it to see if there are marks of injuries, ordering the assembled crowd to observe in order to preclude suspicions" (Mcknight,84).

All body parts of the dead servant girl would be accounted for during the examination, from the crown of the head to the soles of the feet. Injuries found would be measured and the cause of death would be determined. Coroners, starting from the skull to the heels, would then execute the enumeration of bones. The examination would be completed as the fatal point was acknowledged. The results would be announced aloud during the inquest examination conclusion given by the coroner's assistant or attendants. Through this process, the innocence or guilt of the family that hired the servant would be shown to the public. Suspicions between neighbors would also be eliminated due to this procedure, as the examination was completed in front of them. This would maintain the positive relationships between people living close to each other, and also their trust in the authorities. Therefore, social stability can be strengthened with this procedure, as the network between members of a society can be reinforced through the decrease of suspicions.

To avoid biased judgment, Song Ci also recommended in his book that judges should work as independently as possible and be as less exposed to victims' relatives as possible. The officials, clerk and attendants from the initial inquest and re-inquest must not meet or share results revealed by the examinations. Indeed, Song's regulations also stipulated that officials found discussing results could be punished by one

hundred lashes. This was to ensure that officials worked independently. If there were discrepancies between the two inquest results, further investigation would be carried out to ensure that the results match with the corpse. Officials were not allowed to make mistakes, as they could be found guilty of breaking regulation and/or condemning innocent men. This was a serious crime, liable of capital punishment. This 'zero mistake' tolerance for forensic science therefore decreases the possibility of changes being made to results due to bribery.

There was also a strict procedure to be followed when it came to filing and archiving the result of investigations, as Song Ci noted in his book. Officials are to print three copies of each pair of initial inquests and re-inquest results. One copy must be sent to the prefecture or sub-prefecture. Another copy must be sent to the family of the victim. The last copy must be sent to the judicial intendant's office by rapid post. These procedures might have meant more work for the judges, but increased the transparency of the legal system. As a result, people would have a better understanding of the practices of judges and the inner workings of the justice system.

In summary, through more understanding, good relationships between the different groups of people, such as the authorities and common people, can be established. This improves the overall stability of the entire society: "facts speak louder than words, and people have a natural sense of justice" ("事實勝於雄辯,公道自在人心"). Accusations and lies count for nothing when faced against facts, and forensic science provides these facts in legal cases in a society, either in the past or present. All forensic works, such as DNA profiling, blood testing, fiber examination and autopsy are aimed for one purpose: the revealing of truth through scientific method. Freeing one from accusation, clearing one's name, discovering the true wrongdoer or punishing the convict with the right punishment are all results of forensic science work.

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On the Pythian Authority

Lily Lee

The Delphic oracle has significant legitimate agency in *The Histories* – the famous work of historical enquiry written by Herodotus of Halicarnassus. The priestess of Apollo (also known as the Pythia) presided within a crevice of Delphi's sanctuary to give prophecies, and was seen to be "the oracular intermediary with the divine" (Grene) as her words represented the will of the gods. The Pythia held much sway over ancient Greek society, as can be seen by how her advice was actively sought by kings and generals to make important tactical decisions; how her advice was then adhered to; and how her words were able to dispense the ownership of sovereign power.

In the case of uncertainty and indecisiveness in warfare, the advice of the Delphic oracle was often sought to deliver an ultimatum. One of the more famous examples of this is of King Croesus testing the various ancient oracles for authenticity. Having "obtained a true answer" (1.49.7) at Delphi, Croesus proceeded to send messengers to ask if he should "send an army against the Persians" (1.53.3-4) and if he should "take to himself any allied host" (1.53.4-5). It is here where Herodotus shows a direct cause and effect relationship regarding Croesus's inquiry and how the oracle "counselled him to discover the mightiest of the Greeks and make them his friends" (1.53.18-19). In 1.56.5-7, Herodotus describes how Croesus acted in accordance with the oracle's advice.

Another case that shows direct causation between the words of the oracle and tactical decision-making is seen when the Lacedaemonians "inquir[e] of the oracle at Delphi, with their minds set on the whole of Arcadia" (1.66.11-20). After the Pythia advised against this action and suggested for them to attack Tegea instead, "[the Lacedaemonians] let the rest of the Arcadians be, and marched against the men of Tegea" (1.66.22-24). In this instance, the Pythia's words were able to influence even declarations of war.

While the words of the Delphic oracle are typically interpreted in *The Persian Wars* as advice or warnings from a divine source, "many times Herodotus describes the oracular statement as a command or a forbiddance" (Mikalson 55). This indicates that the Pythia was in an elevated position of authority and had the ability to authorize, command or forbid certain things. This ability extended to the dispensing of the ownership of sovereign power, as seen in the instances of Lycurgus's kingship (1.65.22-23) and the Lydian sovereignty (1.13.1-10). The Pythia, having been visited by the lawgiver Lycurgus, deemed him "a god" via prophecy (1.65.16-21) and consequently "declare[s] to him the whole governance of Sparta" (1.65.22-23).

In a more explicit case of the Pythia's ability to validate one's kingship, Herodotus states in lines 1.7.12-15 that "the Heraclidae…… received the sovereignty [of Lydia] and held it in charge, by reason of an oracle", and that Gyges later "took possession of the sovereign power, and was confirmed therein by the Delphic oracle. For... the faction of Gyges and the rest of the people came to an agreement that if the oracle should ordain him to be king of the Lydians, then he should reign: but if not, then he should render back the kingship to the Heraclidae. The oracle did so ordain: and Gyges thus became king" (1.13.1-10).

Many Greek and Roman stories demonstrate that even kings bowed down to the will of the gods. There are two very prominent examples of such "divine command" in the Herodotean narrative: firstly, Alyattes sought the Pythia to shed light on the malady that had befallen him (1.19.8-21.5); secondly, Croesus sought to be allies with Lacedemonia (1.69.6-10). Alyattes, having accidentally burned down a temple of Athene, "fell sick; and, [with] his sickness lasting longer than it should, [sent] to Delphi to

inquire of the oracle" (1.19.8-9). However, the messengers returned bringing news of how "the Pythian priestess would not reply to them before they [restored] the temple of Athene" (1.19.12-14). Then, "straightway [Alyattes] sent a herald to Miletus, offering to make a truce with Thrasybulus and the Milesians during his building of the temple" (1.21.2-5). This shows that a king simply acted upon the implications of the Pythian response with greatest haste, which in turn implies that the Pythian influence equaled – or even triumphed – the whims of kings.

Another case of this is when Croesus offered allegiance to the Lacedaemonians: "'The god [Apollo] has declared that I should make the Greek my friend; now, therefore, as I learn that you are the leaders of Hellas, I do so invite you, as the oracle bids; I would fain be your friend and ally, without deceit or guile'" (1.69.6-10). This is a more prominent example of how a king adhered to the commands of an oracle, clearly showing how kings bowed to the will of the gods.

In conclusion, the Pythia had enough influence to alter declarations of war, dispense the ownership of sovereignty and command even those in the highest positions of power. This is due to the fact that she was seen, in the eyes of men, to represent the will of the gods – especially Apollo's in particular, as he was the patron god of prophecy. The oracle at Delphi was a historical figure with a great amount of influence in *The Persian Wars* – influence so great that it "challenges the king's power" (Barker 8), which thereby shows her significant legitimate agency.

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殺人誅心
—淺析《討武曌檄》的修辭術

吳倩如

內容摘要

本文將以修辭術理論為基礎，分析唐代駱賓王流傳千古的名作《討武曌檄》。看它的語言具有何種程度的雄辯性，如何能有效地說服受眾，支持徐敬業起義。首先，我將分析作者如何以理性論說，利用文章整體建構，突出文章的說服力；其次，看作者使用了何種令人眼花繚亂的修辭手法，達到進一步誅心的目的；再者，我會分析作者是怎樣巧妙利用了當時文化語境中的道德觀念，鞏固了語言的非中立性，從而達到進一步控制受眾的目的 。

本文通過論證得出以下結論：一，駱賓王在文本中能夠有效地運用修辭術，建構其觀點，在當時的文化語境下對受眾有著相當的說服力。以此可見，古代中國在尚未建立類似西方那樣系統的修辭學研究之前，文人們已經對修辭學有著深刻的認知；二，中國古代的雄辯術在儒家文化佔主導地位的社會語境下，發展出了更加重視倫理道德及個人情感的獨特論辯模式。

引言

在西方，修辭學早在古希臘時代就已經成為一個系統性的獨立學科。學術界先後出現了不少如阿里士多德的《修辭學》及尼采的《古修辭學描述》等著作，對修辭學進行深入探討。在中國傳統文化語境中，修辭指的是加強言辭或文句效果的藝術手法，而阿里士多德將修辭術定義為「就每一事物覓出所有可能的說服方式的技能」，即為說服規律的研究，又稱雄辯術。中國歷史上雖然有春秋戰國這些充滿著說客、辯士的時代，卻鮮有學者將說服的學問進行系統化的研究，那麼這是否意味著中國古代文人在辯論中尚不能熟練地運用修辭術這一技巧呢？

一次偶然的機會，我在課外讀到了《討武曌檄》。這篇文章文字的感染力令我深受震撼，使我隱約感覺到此文本具有很高的「修辭術」研究價值。在我選讀的中文課上，我遺憾地發現老師及同學所選取的研究文本多偏向於現代，很少有機會分析古代文獻並展開這方面的討論。在這種偏向當代文本的教學安排下，我感到對中國古典文獻的研究，也許會有獨到的價值並可能引出一些有意義的結論。

本文本圍繞唐代徐敬業起兵對抗武則天時，幕僚駱賓王所撰寫的一篇檄文。此文自流傳以來便以筆力雄健，行文流暢著稱。檄文是古代文體的一種。《說文》曰，「檄，二尺書，從木敫聲。」[1]又有曰，「以木簡為書，長尺二寸，用之號召。若有急，則插雞羽而遣之，故請之羽檄，言如飛之極也」[2]。 由此可見，檄文的主要功用是徵召、聲討，並儘快的速度傳播信息。至於檄文的要求，《文心雕龍· 檄移》中說道：「植義揚辭，務在剛健……必事昭而理辨，氣盛而辭斷，此其要也。」[3]檄文所使用的語言應有感染力及號召力。

本文將以西方的修辭術理論為框架，探討《討武曌檄》如何在文章中將理性論說和藝術修辭相結合，並通過文章中滲透著的儒家倫理價值觀念來影響讀者，體現出其雄辯性。同時，通過分析以得出中國古代雄辯術重情感，重倫理的文體特點。

正文

一，發者與受者

中國古代儒家思想中，有著「君君，臣臣，父父，子子[4]」的嚴格等級規定。君主在萬人之上，廣施仁政。臣子在下則要謹守本分，盡心輔助。在這樣的文化背景下，徐敬業起兵之舉雖說是為匡復唐室，實際上與謀反無異，在道德上已經站在了於己不利的

1 《說文解字》，許慎，中華書局
2 《文體明辨．檄》，明，徐師曾
3 《文心雕龍註》劉勰/范文瀾註，人民文學出版社，2006
4 《論語譯註》第128頁，楊伯峻著，中華書局（香港）有限公司，2009年1月版

一方。常言道，得民心者得天下[5]。如果徐敬業不能解釋他起兵的合理性，便得不到民眾支持，最終必然會失敗。徐敬業作為文本的「發者」，他的「受者」主要有三類。第一，己方。如果己方士兵認為自己是為了正義而戰的話，作戰意欲必定會增加，起義便會有更大勝算。第二，敵方。士兵的士氣對於交戰雙方尤為重要。士氣高昂的軍隊在戰事中將會具有優勢。如果朝廷士兵得知己方君主的暴行，便會覺得自己是為不道德的一方而戰，作戰效率將會減弱，甚至有倒戈的可能。第三，天下百姓。徐敬業必須把自己置於一道德高地，爭取民眾及駐守各地的宗親及將領的支持，令他的軍事行動有更大的助力。如果他們響應起兵的話，起義將會事半功倍。由此可見，此篇檄文的受眾的範圍和類別十分龐雜，但我們又可以從下文的分析看出，這個文本對於這些截然不同的群體，都有著相當的煽動力。

二，理性論說

阿里士多德在《修辭學》中，將說服的手段歸為「證明」。證明分為人為證明與非人為證明。非人為證明指的是已經存在的條件，而人為證明需要靠發者自行「創造」。人為證明又分為信譽證明、情感證明、及邏輯證明[6]。拿普通人所熟悉的「議論文三要素」相比較，「非人為證明」的定義接近論據，而「人為證明」的定義則更接近論證。

首先，文本中用了許多非人為證明來顯示武后如何罪大惡極。文章一開始，作者便開門見山地以一個「偽」字來界定武后掌控政權的非法性。提筆便下了如此強烈的結論，先發文章的鏗鏘之聲。之後作者又提到武后身份卑微（地實寒微），品行不檢（穢亂春宮），心腸陰毒（掩袖工讒），性格殘暴（弒君鴆母）。這裡的描寫雖然大有失實之處，尤其是「弒君鴆母」一事在史書之中從未記載，但普通老百姓未必知道宮中之事，加上之前的文字描寫了武后心腸狠毒，使整篇文讀起來大有先聲奪人的氣勢。就算其中論據失實，受眾亦無從也難以追究。

其次，在人為證明方面，作者先是動用了信譽證明（喻德）的方法。信譽證明即以人物的信譽或素質作為論說中心，以此說服受眾[7]。由於文本受眾對於宮廷之中發生的事情難以通過確切的來源加以得知，因此他們會傾於相信那些平常有權威、受尊重的人們的有關言論。文本中，作者以忠臣之後（公侯冢子），原因合理（爰舉義旗，以清妖孽），順應民心（順宇內之推心）為由，將己方置於道德高地。相比之下，武后身份卑微而心腸惡毒，不可信任。信譽度的對比使文章徒增了不可置疑的說服力。

其次，情感證明（喻情）也是文本中使用的另一件利器。情感證明即以感動受眾來達到說服目的[8]。作者在文本中激發了受眾的數種感情。首先描述武后違背人倫的惡行，令人義憤填膺，還引起了民眾對暴政的恐懼；其後描述起義軍撼動山河之勢，令人熱血沸騰。然後提起大臣宗親受先帝之托（或膺重寄於話言，或受顧命於宣室），又指出先帝屍骨未寒，遺孤無托的慘狀（一杯之土未乾，六尺之孤何託），令讀者想到先帝大業，不禁潸然淚下。阿里士多德說過，「人們在愉快和友好時做出的判斷不同於人們在煩惱和敵對時做出的判斷。[9]」而文本中所調動的受眾感情，正能令人作出有利於發文者的判斷，增加文章的感染力。這一點本文會在之後進一步論證。

另外，作者在檄文中也使用了邏輯證明（喻理）的方法。邏輯證明即以推理邏輯說服受眾[10]。文中作者首先用類比論證，舉出女性掌權後亡國的後果，令人以歸納法聯想到女人把持朝政，亡國是必然後果。描述武后惡行後引申到「人神共憤，天地不容」，屬於道理論證，即以人們普遍認同的價值觀來證明觀點。作者還使用了對比論證，即利用結構上的對比來營造武后與徐敬業之勢不兩立，正與邪之間存在二元對立，顯得兩者之間正邪分明。我們可以將文章從開頭到「識夏庭之遽衰」分為第一段，「敬業皇唐舊臣」到「以此圖功，何功不克」分為第二段。第一段把武后描寫成殺害至親，窺竊皇位的負面形象。第二段為徐敬業冠上名將之後，順應民心等道德光環。作者利用語言營造出兩人之間的強烈對比，為武后貼上卑鄙可恥的標籤，相反徐敬業就更顯高尚。受眾在心中會下意識地認為，武后的一應所為都是可鄙的，而

5《孟子離婁上》「得天下有道，得其民，斯得天下矣。得其民有道，得其心，斯得民矣。得其心有道，所欲與之聚之，所 惡勿施爾也。」《孟子100名言》第110頁，王壽延著，中華書局（香港）有限公司，2007年4月版

6《說服學一攻心的學問》第27頁，龔文庠著，人民出版社，1998年2月版

7《說服學一攻心的學問》第15頁，龔文庠著，人民出版社，1998年2月版

8《說服學一攻心的學問》第16頁，龔文庠著，人民出版社，1998年2月版

9《說服學一攻心的學問》第16頁，龔文庠著，人民出版社，1998年2月版

10《說服學一攻心的學問》第17頁，龔文庠著，人民出版社，1998年2月

徐敬業的所為代表著正義一方。在此心態之下，立場自然會傾向於起義一方。

三，修辭手法與語言傾向性

如上文說，作為檄文，雖然這種文章類型注重某種實用性，但如果沒有語言藝術上的高度修飾，就只會顯得枯燥無味。文章的藝術性會增強其觀賞性，令受眾產生強烈的閱讀意欲，進而增加文章的流傳度。尼采於《古修辭學描述》中說道，「修辭術的真正秘密仍在於誠摯與藝術性兩者的審慎明智的結合。一旦不加修飾，就會冒犯聽眾的藝術鑑賞力。[11]」除了增加文章的流傳度，藝術手法也可以進一步加強語言的非中立性和煽動力。而最能夠體現這種藝術手法的，就是修辭手法的運用。文篇檄文使用的修辭手法大致包括:

1.比喻

比喻即利用不同的事物之間的相似點來作比較。此手法可令事物更為具體及形象，也可以令深奧的道理看起來較為淺顯。[12]

加之虺蜴爲心，豺狼成性

這裡將武后比作兩種動物，指她心地如毒蟲般歹毒，如豺狼般貪婪殘忍，將心腸狠毒這一人性特點形象化。

2.用典

用典即引用古籍中的詞句或歷史上已經發生的事例和目前的狀況相比，利用歷史的重復性來預示未來或諷刺現實，同時還可以省略繁復的描述，令語言更為精簡。[13]

燕啄皇孫，知漢祚之將盡。

這裏的燕啄皇孫，指的是東漢成帝皇后趙飛燕因自己不能生育而殺害所有懷孕的宮人。此處暗指當年武后為了成為皇后，殺死親生女兒，誣陷王皇后的傳言。此處用典的目的是為提醒受眾如果任由武后掌權，最終唐朝也會走向衰敗，由此激起受眾的危機感，令他們支持起義。

一杯之土未乾，六尺之孤何託。

此處作者引用了論語中的「可以托六尺之孤……君子人與？君子人也。[14]」的詞語，意指「可以託付孤兒的人是君子嗎？當然是君子。」由此勸喻大臣們於情於理都應該支持徐敬業起義。

3.誇張

誇張即對事物的特徵進行誇大或縮小，以達到強調效果。一般來說，帶有議論性質的文章需講求理據翔實，論點要有事實根據，避免使用誇張手法。[15]但在此文本中，作者利用了誇張手法營造出一種磅礴和壓倒性的氣勢，令文章更具說服力。

南連百越，北盡三河；鐵騎成群，玉軸相接……匡復之功何遠？

此處作者描寫了從南方越地到中原三河，都是徐敬業的鐵騎，戰車多到車軸相接的景象。雖然實際上這種情況不可能出現，但文字給予了讀者強烈的畫面感，令讀者感受到起義軍推翻武后暴政的決心。到最後，作者反問一句：成功匡復皇室的時候還遠嗎？隨著前面的鋪墊，這句反問有著「不遠」這毋庸置疑的答案。這段的誇張效果能令本來對起義態度搖擺不定的受眾支持起義一方，文字中的威勢提高了文本整體的說服力。

除了用以上的修辭手法以增強語言的渲染力，作者還利用了語言的導向性，使受眾在不知不覺中改變觀點。

昔充太宗下陳，曾以更衣入侍……潛隱先帝之私，陰圖後房之嬖……掩袖工讒狐媚偏能惑主……陷吾君於聚麀。

若非李治在當太子的時候對父皇的妃嬪暗生情愫，若非後來高宗執意接武媚娘回宮立為皇后，武后根本沒機會掌權。但在文中，作者為了維護李唐皇室一方的聲譽與道德，將這段不正當關係的責任推到武后「掩袖工讒」、「狐媚惑主」上，完全沒有提到李治之過。在當時男尊女卑的文化語境之下，受眾看到這一段，不可避免地認為武后陷先帝於不義，其罪當誅；而高宗作為被

11《古修辭學描述：外一種》第51頁，弗裡德裡希尼采著，屠有祥譯，上海人民出版社，2001年版
12《古漢語修辭》第83頁，余章成編著，中國社會科學出版社，2011年8月版
13《古漢語修辭》第115頁，余章成編著，中國社會科學出版社，2011年8月版
14《論語100名言》，趙炳臣著，2006年
15《古漢語修辭》第153頁，余章成編著，中國社會科學出版社，2011年8月版

迷惑的一方，其罪可恕並且值得同情。因為帶著對李唐皇室的感情，受眾理所當然會將心中的天秤傾向聲稱匡復唐室的徐敬業一方。

四，文化語境中的語言色彩

上文提到，要有效地說服受眾，就必須掌握受眾心理。而受眾的心理是與當時的文化語境相關的。人們之所以會在某些言論面前被感化，原因之一正因為其內容往往與當時社會流行的價值觀相符，令人覺得所言道出了民眾之所想。

儒家自春秋戰國時興起，到漢武帝罷黜百家獨尊儒道，二千多年來在中國佔有絕對的思想主導地位，鑄造了普通中國人的道德倫理觀念。初唐時期對外文化交流頻繁，令許多來自西域的宗教（佛教，祆教等）影響了人們的思想。雖然李唐皇室尊奉老子，令道教的影響力增加，但是儒家思想仍然根深蒂固，難以撼動。更何況儒家思想有利於專制君王統治，皇帝也始終尊崇儒家在民眾思想中的重要地位。文篇檄文滲透著相當多的儒家思想，總結說來有：

1.忠君愛國

「君使臣以禮，臣事君以忠。」[16]在儒家思想中，臣子應當以忠心服侍君主，如諸葛亮一般，對君主做到「鞠躬盡瘁，死而後已」[17]。在文本中，作者提到眾臣受朝廷厚恩，故理應以天下為重，「共立勤王之勳」，正是這種忠君愛國觀念的體現。此觀念針對的受眾主要為當朝大臣，讓他們意識到繼續輔佐武后實為不忠不義之舉，勸說他們應盡臣子之道，群起反抗武后。

2.仁義

「人之所以異於禽獸者，幾希，庶民去之，君子存之。」[18]「惻隱之心，人皆有之。」[19]儒家的思想將「仁義」及「惻隱之心」列為最基本最重要的人性。然而，文本中的武后將親生骨肉「幽於別宮」，妒忌心重（入門見嫉，蛾眉不肯讓人）。如此描述，將武后推至反人性的禽獸之類，以此影響受眾，號召他們將此等不仁不義的妒婦推翻。

3.禮教

《禮記》為儒家四書五經之一，集中體現了儒家對禮法的重視。荀子認為，禮儀有著「養」，「別」、「群」三種作用。其中的「別」，便是維護等級秩序及人與人之間的區別（長幼尊卑）。文本中的武后先是「陷吾君於聚麀」，「弒君鴆母」，又「窺竊神器」，逾越了男女，長幼，君臣，父子之間的界線。除此之外，武后還違反了當時社會尤為重視的門第觀念。門閥制度在魏晉南北朝時期達到鼎盛，當時有著「上品無寒門，下品無望族」之說。這種門第觀念延續到唐代，影響依十分深遠，不少人依然視攀上豪門為榮耀。文章第二句就直指武后「地實寒微」，在當時的社會文化潮流面前，更顯得當朝的武后名不正言不順。在重視禮法門第的社會風氣下，受眾會很自然地對武后的作為產生抗拒心理。

4.個人修養

個人修養是儒家思想的重要組成。「古之欲明明德於天下者，先治其國；欲治其國者，先齊其家；欲齊其家者，先修其身……」[20]儒家思想中，若要治國平天下，最根本的便是要從自身修養出發。在文本中，武后被指罵為道德淪喪，心腸狠毒，殘害骨肉的人，連最基本的「正心、誠意、修身、齊家」都做不到，更何況掌握朝政，「治國、平天下」？

5.性別

「婦人有三從之義.....未嫁從夫，既嫁從夫，夫死從子。」[21]儒家思想中性別思想的核心，就是要女人對男性的服從。武后越過丈夫及兒子掌握實權，顛覆了傳統的性別定位。作者指她曾侍二君，狐媚惑主，又以歷史上的奸妃與武后對比，由此對她的掌握政權的能力進行鄙視，將她視為禍水。在流行的「男尊女卑」大男人主義的觀念下，影響檄文受眾對武后的看法。

五，音樂性

《討武曌檄》的文體屬於駢文。駢文於南北朝時期興起，至隋唐達到興盛時期。「駢」的本意是兩馬並駕一車，進而延伸到文章中規範地使用對偶這一特點。除此之外，駢文也十分講究音律，每句多為四字或六字。

16《論語譯註》第46頁，楊伯峻著，中華書局（香港）有限公司，2009年1月版
17諸葛亮《後出師表》《古文觀止》第23頁，吳調侯及吳楚材著，商務印書局（香港）有限公司，1998年12月版
18《孟子100名言》第136頁，王壽延著，中華書局（香港）有限公司，2007年4月版
19《孟子100名言》第77頁，王壽延著，中華書局（香港）有限公司，2007年4月版
20《親子文學坊8—大學》第13頁，張欣卉著，大千文化出版事業公司，1998年9月版
21《四庫全書一儀禮集釋》第214頁，李如圭著，古籍出版社，1987年版

潛隱先帝之私，陰圖後房之嬖

以這一句為例，動詞「潛隱」對應「陰圖」。名詞「先帝」對應「後房」，「私」對應「嬖」。每一分句都是六字，整齊劃一。

為求節奏工整，駢文還要求押韻及句子之間平仄工整。但是，此篇文本有些地方卻沒有顯出這個駢文的特點。

昔充太宗下陳，曾以更衣入侍

這一句的平仄是「平平仄平仄平，平仄平平仄仄」，即使換成古四聲也是「仄平仄平仄平，平仄通通仄仄」。平仄並不相對，而且「陳」與「侍」也不押韻。

那麼，作者是如何把握文本的節奏感的呢？如果我們將文章朗讀出來，找出句子中的重音，就不難發現，每相應的兩句，他們除了字數一樣之外，重音也在同一位置。而且每一組句子重音的位置不盡相同。這樣工整的排列令文章讀起來出現了自然的節奏感。行文中見整齊，整齊中見變化，既不造作，又朗朗上口。例如：

入門見嫉，蛾眉不肯簠人。揎袖工讒，狐媚偏能惑主

因為有著如此嚴謹的格式，駢文對於作者的文學技巧要求很高。駱賓王的這篇文章看起來整齊美觀，讀起來節奏鏗鏘。雖沒有刻意追求押韻或平仄相對，也有著很強的節奏感，讀起來有著自然的抑揚頓挫，朗朗上口，增加傳唱度。可以想見，當時人讀到這篇「美文」的時候，其高超的文字技巧，無形中透出一種巨大感染力和鼓動力。

結論

綜合上文分析，《討武曌檄》的作者重視理性與感性的結合，但更加重視感性言說。在文采斐然，華麗和令人炫目的修辭手法下，文章的感染力徒增。其作者根據當時社會的意識形態對民眾心理進行了敏銳的捕捉，使文章上下在充滿了浩然正氣的同時又具有尖銳的道德譴責。其富有節奏感和音樂性的行文風格，更進一步提升了內容的感染力。由此可見，《討武曌檄》充分展現了中國古代文人在修辭學理論尚未系統化的情況下，對雄辯術技巧的熟練運用和掌握，而且在實踐中深植於東方文化語境，對受眾有著從道德以致情感的強烈感染力。

值得注意的是，檄文作者在文本中主要攻擊的並非武后的當朝政績，而是武后的個人品格以及她的性別血緣。作者也大量使用了如「六尺之孤何托」等情感示例，作為徐敬業攻擊武后出身所提出的非人為證明。因此，就宏觀而言，我們由此看出中國雄辯術不同於西方雄辯術的一些特點，即中國的雄辯術在儒家文化語境下，發展出了以倫理道德及個人情感為主要說服手段和立論手段的獨特模式。

有著這篇檄文的助力，起義開始的時候徐敬業的大軍的確勢如破竹，但不久就因戰略錯誤，久戰兵疲而潰敗。隨著起義軍的失敗，駱賓王此人也消失在了歷史的舞台上，只留下了這篇流傳千古的《討武曌檄》。當時武后看到這篇檄文時，一開始還不以為意，但看到「一杯之土未乾，六尺之孤何托」這一句時大吃一驚，感嘆朝廷不能招攬此等人才乃丞相之過。《古文觀止》的編者吳調侯及吳楚材點評此文時說道，此文「雄文勁采，足以壯軍聲，而作義勇，宜則天見檄而嘆其才也。[22]」足見歷代文人對此文的高度評價。

22《古文觀止》第302頁，吳調侯及吳楚材著，商務印書局（香港）有限公司，1998年12月版

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附錄：文本《討武曌檄》 選自《古文觀止》

僞臨朝武氏者，性非和順，地實寒微。昔充太宗下陳，曾以更衣入侍。洎乎晚節，穢亂春宮。潛隱先帝之私，陰圖後房之嬖。入門見嫉，蛾眉不肯讓人。掩袖工讒，狐媚偏能惑主。 踐元後於翬翟，陷吾君於聚麀。加以虺蜴爲心，豺狼成性。近狎邪僻，殘害忠良。殺姊屠兄， 君鴆母。神人之所共嫉，天地之所不容。猶復包藏禍心，窺竊神器。君之愛子，幽在別宮。賊之宗盟，委以重任。嗚呼！霍子孟之不作，朱虛侯之已亡。燕啄皇孫，知漢祚之將盡；龍蓼帝後，識夏庭之遽衰。

敬業皇唐舊臣，公侯冢子。奉先君之成業，荷本朝之厚恩。宋微子之興悲，良有以也。袁君山之流涕，豈徒然哉！是用氣憤風雲，志安社稷，因天下之失望，順宇 之推心，爰舉義旗，以清妖孽。

南連百越，北盡三河。鐵騎成群，玉軸相接。海陵紅粟，倉儲之積靡窮。江浦黃旗，匡復之功何遠！班聲動而北風起，劍氣沖而南斗平。喑嗚則山嶽崩頹，叱吒則風雲變色。以此制敵，何敵不摧？以此圖功，何功不克？

公等或居漢地，或葉周親，或膺重寄於話言，或受顧命於宣室。言猶在耳，忠豈忘心。一杯之土未乾，六尺之孤何託？儻能轉禍爲福，送往事居，共立勤王之勳，無廢大君之命，凡諸爵賞，同指山河。若其眷戀窮城，徘徊歧路，坐昧先幾之兆，必貽後至之誅。請看今日之域中，竟是誰家之天下！

How did the Chinese flute develop over time and why did the dizi change so significantly during the Song Dynasty?

Matthew MacGeoch

The oldest instrument found to date is a flute, made 42,000 years ago. Since then, many cultures throughout the history of mankind have created flutes for different uses. From religious rituals to cultural ceremonies or even entertainment, the use of the flute has been continuous. The transverse flute did not undergo major changes in either China or Europe until the nineteenth century. Before the nineteenth century, the western classical flute was very similar to the Chinese flute. Both instruments were constructed from wood[1], had six or seven holes, featured a carved or drilled hole to blow across and had few or no keys. During the first half of the nineteenth century, a German inventor and musician called Theobald Böhm (also spelled Boehm) developed a key mechanism, thereby turning the relatively basic and diatonic flute to the fully chromatic flute now used in concerts and orchestras around the world.

The first versions of the Chinese flute, called the *dizi* (笛子), that have been excavated are from the Neolithic Era (10,200BC-4,500 BC), found at Hemudu (河姆渡). These flutes generally had one or two finger holes to create different notes (金文達, 68). One other noticeable feature is that the bones from the flutes had been rubbed so that they were very smooth. From this, we may deduce that the owners of these flutes took very good care of them and valued their instruments.

The first documented evidence for the use of the Chinese flute comes from the Zhou Dynasty (1046–256 BC) when it was called a *chí* (篪) and was mainly used as a court instrument to entertain the emperor (Brindley, 26). In addition, Brindley states that "wooden instruments [such as the flute], when they appeared without bells and chime stones [in tombs], were generally separated from ritual vessels and placed in a side compartment. Such an arrangement seems to signify their use in warfare or more private forms of entertainment." Apart from these uses, there is also evidence to suggest that the flute was used by the military, possibly to help send messages over long distances or to send commands to the troops quickly and efficiently. (Brindley, 26)

The next record for the Chinese flute comes from the beginning of the Han Dynasty (206 BC – 220 AD). It was during the Han Dynasty that the flute became known as the *di* (either 笛 or 篴). At this time, a transverse flute, referred to as the *hengchui* (横吹), was also imported from the modern Xinjiang region. This flute also had six finger holes, but did not yet have the membrane hole to create the well-known buzz in the tone of the dizi. This flute would most definitely have influenced the design of the dizi as the previous type of dizi only had four or five finger holes (Dien, 352). A recent excavation in Guangzhou found six transverse flutes from the Western Han Dynasty (蕭興華, 159).

During the Han Dynasty, the Emperor Wu of Han, also known as 漢武帝, commissioned a mid-range flute. This was because at the time there was a short flute, which played the higher octaves, and a longer flute, which played lower octaves, but there was no flute that could play the notes in between. Also, on an old bridge in Zhengzhou, Henan Province, paintings and icons of characters playing the transverse flute dating back to the Western Han Dynasty have been found (蕭興華, 160). Seven-holed flutes from the same time period have also been found in a tomb in modern day Gansu Province (劉東升, 120). A man called Qiu Zhong (丘仲), was commissioned to make a flute that had seven finger holes and was also two feet and for intervals smaller than the tone intervals common at the time. This new flute was roughly one foot and eight inches long (金文

1 The Chinese most commonly used bamboo to make their flutes. In Chinese culture, bamboo is neither plant nor wood, but is in between a type of plant.

達, 231). Illustrated evidence found on wall paintings and stone rubbings show that the dizi was an important military instrument at the time, often used in battles. This shows the importance of the dizi in Chinese society at the time. During the Han Dynasty, there was also a type of ensemble developed called the *guchui* (鼓吹), which consisted of percussion and wind instruments. In this ensemble, the dizi would be the leader of the wind section and very often have the main melody line when there was one. This showed that not only was the dizi rated highly in society, but also amongst other instruments in the ensemble. (金文達, 147)

Right after the Han Dynasty, the dizi became especially popular with the common people because of the simple, cheap and quick construction, the lightweight design and also the ability to play it almost anywhere (Moule, 80).

The next record of the dizi in Chinese history comes from either the Three Kingdoms or the Jin Dynasty. A tile was found by archaeologists inside a grave in Dengxian鄧縣, Henan Province, on which there was a carving of people playing several instruments, one of the instruments being a transverse flute (金文達, 352). This shows the important role of music in the deceased's life since he wished to have images of music with him even after he died. From this, we can also understand that from the Han Dynasty people valued music.

By the Tang Dynasty (618-907 AD), flutes of different sizes had been developed for different keys and octaves. The *Wenxian Tongkao* 《文獻通考》 (*Comprehensive Examination of Literature*) states 「大橫吹、小橫吹，並以竹為之，笛之類也」. This line describes how there would have been larger, longer flutes to play lower-pitched octaves and thinner, shorter flutes to play octaves and different sized flutes for the different scales and octaves in between. During the Tang Dynasty, the flute was also exported to Japan and Korea thanks to the increased trade between these countries. The original design of the Tang flute lasts through to this day via the Japanese traditional Gagaku Orchestra, where the flute is known as the *ryūteki* (also called ōteki).

During the Song Dynasty (960-1279AD), as the taste in music of the imperial government became more traditional, so did the design of the dizi (Thrasher, 94). By 'traditional', I mean that the taste in music became similar to older styles of music, such as music from pre-Tang Dynasty. During the Song Dynasty, the dizi returned to the six-hole design, removing the extra range and smaller intervals the seven-holed flute (created in the Han Dynasty) allowed for. Also, the flute received its *di-mo*（笛膜）or membrane that gives it the iconic shrill sound when played. At this time, a second name also emerged for the flute, the *qixingguan* 七星管 ("Seven Star Pipe")(Moule, 80). This name is understood to refer to the six finger holes, as well as a membrane hole to make seven holes.

During the Yuan Dynasty (1271-1368), flutes were painted green with red bands because green would represent the bright and energetic sounds that the flute makes that were also associated with spring, the 'green' season in Chinese culture. The red would then symbolise the powerful and uplifting tunes that the flute could create, sometimes when used in the military.

It was during the Ming Dynasty that the dizi started to become a prominent solo instrument instead of being played together in a group. It was during this period that a series of pieces were composed for the dizi, accompanied by a drum. This pairing is known as *chuida* 吹打 (literally translates to "Blow-Hit"). It was also during this period that the dizi joined the louder sections in an orchestra to give an extra degree of thrill to religious celebrations and also military music. This was continued during the Qing Dynasty.

During the Republic of China era, amateurs and buskers still commonly used the flute. The instrument was also used at weddings, funerals and religious services and used by fortune-tellers, Taoist priests and a particular sect of Buddhists[2]. At this time, the dizi was also the most common instrument with a fixed pitch and was popular with people of different social classes due to its cheap cost to make and simple design (Moule, 78-79).

2 To accompany the *kunqiang* 昆腔 (kūn qiāng) music.

Since the Republic of China Era, there have only been minor changes to the design of the dizi. For example, the alignment of finger holes has changed, so that the intonation and scales produced on the Chinese flute match those of the Western flute during the late Qing Dynasty and early Republic of China era. This was done so that the dizi could attract foreign players and also play with foreign instruments.

In the modern day, the dizi acts as a leader in wind and percussion ensembles common in Xi'an, as well as Silk and Bamboo ensembles common in Jiangsu (this latter name comes from the materials of the string and wind sections respectively) (Jones, 91). The dizi represents the 'civilian' part of the repertory compared to the Chinese shawm, which is used for the more 'martial' sections. Also, the dizi is more commonly used in the southern parts of China in ensembles, whereas in the North it appears only occasionally with ensembles and is more commonly seen as a solo instrument.

I would now like to focus on the Han and Tang Dynasties when the dizi came the closest to the western chromatic flute, and also why the dizi returned to the more traditional diatonic scale during the Song Dynasty.

During the Han Dynasty, the dizi was further developed and greatly diversified with different models of dizi to play different octaves and keys. This allowed for it to be incorporated into many different ensembles on a wide range of pieces and created more opportunities for dizi players to play.

Secondly, the Tang Dynasty was a period of great development in the arts and was similar to the Renaissance in Europe. This would have been due to the diversity of people, religions and cultures that were able to congregate and share different ideas, skills, arts, and most importantly, forms of music. During this period of time, people had increased self-confidence in their ability to create new and different ideas, without the fear of rejection and failure. This should have contributed significantly to the development of the dizi. There was also a development in all aspects of the arts. Musicians developed a dizi capable of playing a full chromatic scale, using a half-holing technique. This essentially unified all the diverse range of flutes.

This technique was achieved by not using the fingertips to cover the finger holes, like on modern Chinese flutes and western flutes, but instead by covering the holes using the 'body' of the finger. This technique of covering the holes allowed for easier "half holing" on the seven-holed dizi. There is one book of music specifically written for the flute from this period. This book is called the *Boya dipu* 《博雅笛譜》(*The Educated Flute Score*, Hakuga fue-fu in Japanese)[3]. This piece of music was notated in tablature format. This particular form of notation advocates using the fingerings on the dizi (using Chinese characters) instead of notating the pitch of the notes. The advantage of this form of notation allows the tune to be played in all keys easily without having to transpose an instrument.

Throughout this book, there are pieces for the dizi in different keys; the more commonly seen keys are the equivalents of modern day C Major, G Major, D Major and A Major. This book was created to be used in the Tang court, where musicians would entertain the emperor, his family and the ministers of the court would relax and sometimes, would be played during official ceremonies. Countless other pieces of music for the dizi were written for the Tang court, including an equivalent of an overture, a prelude and another section called "broaching". The sophistication of the dizi and dizi music was held in such a high regard that even the emperor would have it played to him often.

But then why did the dizi change during the Song Dynasty?

During the Song Dynasty, there was a demand for more traditional music. This led to the return of the six-holed dizi that was not able to play the full chromatic scale. Possible reasons behind this change of taste in music could be that after the chaotic and troubling Five Dynasties and Ten Kingdoms period (五代十國), the government and the people might have wanted a familiar style of music that stuck to the well-known scale and therefore always sounded in tune rather than having experimentation and dissonance in tunes and

3 This has only been preserved through its shipment to the Japan during the Tang Dynasty, where it was preserved to this day together with the Tang Flute, known in Japan as the *ryūteki* along with an ensemble of instruments from that era called the *Gagaku orchestra*.

harmonies. This was found in music overall, but could be found in ensembles, such as the *guchui* 鼓吹 (consisting of wind and percussion) and the *sizhu* 絲竹 (consisting of silk and bamboo instruments). The return of the six-holed dizi would have then forced the creation of several different dizi in different keys so as to be able to play with other instruments in more than a select few pieces. This particular dizi underwent minor changes during the rest of the Song Dynasty, the Yuan Dynasty and the Qing Dynasty, such as changing the colour to match the contemporary imperial colour of the time and other minor changes. This dizi is very similar to the modern dizi.

Over the past three thousand years, the dizi has contributed to the Chinese orchestra and also to Chinese culture significantly. This essay shows that this traditional instrument has had a long and dynamic history; from the basic four-holed diatonic dizi to the fully chromatic seven-holed dizi during the Tang Dynasty, and the return to the six-holed dizi during the Song Dynasty, with the change in style of music and a reduction of experimentation in music. We cannot fathom the reason for this change with certainty; it might be explained by the desire for stability after a long period of political turmoil, as well as by the technical need to tune the instruments accurately. Finally, the western-tuned six-holed dizi was introduced to China in all its different shapes and sizes, and the popularity of dizi is maintained to this day.

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「樂」、「藥」與嵇康的避世思想

陳嘉懿

始於東漢末年的三國之爭，以西晉統一中國為句點。自始，政權更迭頻繁，多國並存，直至隋文帝楊堅再統中國。這個短暫的、承上啟下的時期便是魏晉南北朝。這個朝代踴躍出了大批名士，例如「正始玄學」代表人物何晏、王弼；「竹林七賢」嵇康、阮籍、山濤；「五柳先生」陶淵明；道教名醫葛洪、陶弘景。這些隱士具有超脫個人的氣度、加之生活具有神秘色彩，令人十分嚮往。其中，嵇康在思想方面有著極高的造詣，位列「竹林七賢」之首。迄今，史學界、文學界已對嵇康進行了全面深入的分析研究，但對一般讀者而言，他具有代表性的「樂」與「藥」的思想，卻需要進行簡要和概括的學術梳理。此文將會著重探討嵇康在「藥」與「樂」方面的言行，並從中探討這些言行反映出的其避世思想的影響。

嵇康生活的年代正值曹魏交替，政局混亂，史料中記載了諸多司馬一氏與曹氏的明爭暗鬥。「嵇康與魏宗室婚，拜中散大夫。」（《晉書・嵇康傳》）其妻是曹魏的長樂亭主，因此，他是與曹魏有宗親關係的大人物，被捲進了這場紛爭。然而，他卻對這種險惡的現實政治十分反感。其在《五言贈秀才詩》中寫道：「鳥盡良弓藏，謀極身必危。吉凶雖在己，世路多嶮巇。安得反初服，抱玉寶六奇。」在這裡，他對即將要出仕的兄長並沒有抱著十分積極的態度，相反，他卻說官場險惡，智慧和計謀並不一定要用在這個世道上，並且自己無法掌控所有的福氣禍端。嵇康無法找尋到他理想中的社會風氣，所以他甘願避世，並告誡哥哥謹言慎行。這種「避世」態度，首先是為保護個人安全和人格清白，是對當時險惡的政治現實的消極逃避。其以隱居不仕作為保持人格清白之唯一途徑的思想，還表達在著名的《與山巨源絕交書》中：「山公將去選曹，欲舉嵇康；康與書告絕。」（《世說新語・棲逸》）嵇康與山濤關係十分親密，山濤敬重其才華橫溢，向司馬氏舉薦嵇康。嵇康聽聞後，對好友不理解自己的心境感到十分失望，氣憤之下就作了此書。他在其中寫道：「故君子百行，殊途而同致，循性而動，各附所安……又縱逸來久，情意傲散，簡與禮相背，懶與慢相成，而為儕類見寬，不攻其過。又讀《莊》、《老》，重增其放，故使榮進之心日頹，任實之情轉篤。」（《與山巨源絕交書》）嵇康在這裡強調他自己行為簡慢，性情懶惰，與禮法相悖。在讀完《老子》和《莊子》之後，追求榮譽的心性日益頹廢，而然放任率真的本性則日益加強。「自然」的放任率真，令他斷然拒絕好友的邀請，不願與官場中人同流合污。從下文我們可以看到，這樣的生活背景以及由此產生的處世態度，對嵇康在「樂」與「藥」兩方面的行為、思想都產生了很大的影響。

「嵇中散臨刑東市，神氣不變。索琴彈之，奏廣陵散。曲終曰：『袁孝尼嘗請學此散，吾靳固不與，廣陵散於今絕矣！』太學生三千人上書，請以為師，不許。」（《世說新語・雅量》）今人對嵇康音樂上成就的了解大多止於一曲《廣陵散》，殊不知，音樂是其對更高人生境界的追求。除了識奏人間絕響《廣陵散》，嵇康在音樂思想方面的造詣也頗高，著有《琴賦》、《聲無哀樂論》。他曾在《琴賦並序》中寫道：「余少好音聲，長而玩之，以為物有盛衰，而此無變；滋味有厭，而此不捲力。可以導養神氣，宣和情志，處窮獨而不悶者，莫近於音聲也！」[1] 從小喜愛音樂的嵇康，長大後修習撫琴。他認為能使人

1 嚴可均編：《全三國文》，卷四十七。

身處困境而不會無所事事的東西在這世間只有音樂了。他對音樂的深度認知，更多地體現在其音樂美學思想中。他的《琴贊》的內容是這樣的：「懿吾雅器，載樸靈山。體具德貞，情和自然。澡以春雪，澹若洞泉……宣和養氣。」[2] 嵇康對於音樂追求「自然」，認為自然不以人的意志和價值為轉移，相反人的藝術境界以情感的自然流露為高。同時代人形容其音樂風格為「高奇見貴」：「或問顧長康：『君箏賦何如嵇康琴賦？』顧曰：『不賞者，作後出相遺。深識者，亦以高奇見貴。』」（《世說新語・文學》）這又再次體現了其對「自然」的追求，崇尚個人情感，追逐最純粹的音樂。在他的《聲無哀樂論》中，他指出：「心之與聲，明為二物。」「聲音自當以善惡為主則無關於哀樂，哀樂自當以感情而後發，則無繫於聲音。」[3] 在這篇文章中，嵇康將聲音與人的情感加以區分，他認為音樂發出的只是客觀的音調，不帶有任何感情色彩，而所謂的哀樂則是出於人的內心，是主觀的情感。主觀的情感是不會去影響客觀的音調的。如上文所提到他的避世思想，嵇康音樂上的這種音樂思想正體現了其超然灑脫，不受外界的影響的淡然作派。

作為「魏晉風度」的代表人物，嵇康的音樂思想，如魯迅先生所說，與「藥」有著密切關係。《晉書・嵇康傳》中提到嵇康「常修養性服食之事」（《晉書・嵇康傳》），其兄所寫《嵇康傳》也說他「性好服食，常採御上藥」，可見，服「藥」是其生活中的一個重要部分。魏晉時期文人最流行服食「五石散」，嵇康位列「竹林七賢」之首，在服食「五石散」上更具有代表性。「魏晉時人的五石散方係由東漢名醫張仲景的兩個方子『侯氏黑散』和『紫石寒食』合併加減而成。『五石』指的是紫石英、白石英、赤石脂、石鐘乳和石硫磺……《神農本草經》把五石散中的白石英、紫石英、石鐘乳、赤石朧列為上品之藥。」[4] 五石散的副作用很大。當藥性發作時，整個人會變得焦躁不安，皮膚異常燥熱敏感，只能穿柔軟而薄寬的衣服。同時，必須行走並配以溫酒來散發藥性，即所謂的「行散」。副作用之強大在隋巢元方《諸病源候總論》中有所記載，晉代名醫皇甫謐長期服食「五石散」後自述：「隆冬裸袒食冰，當暑煩煩，加以欬逆，或苦溫瘧，或類傷寒，浮氣流腫，四肢酸重，……救命呼噏。」（《晉書・皇甫謐傳》）既然「五石散」會讓人生理異常痛苦，那為何嵇康仍舊服食呢？

關於五石散的功用，魏晉時期的一些名士有過各種表述。如「何平叔雲：『服五石散，非唯治病，亦覺神明開朗。』」（《世說新語・言語》）此外，「魏晉之際，隨著理性精神的復歸和崛起，生與死的對立已處於前所未有的緊張狀態，樂生厭死的觀點逐漸成為時代思潮的主旋律……服食風氣的盛行與神仙、養生思想的信仰有密切關係，體現的是一種人生欲求的強烈衝動……在魏晉時期人們的信念中，金石是恆久的象徵，人若服食金石，便能將金石恆久的因素攝入體內，進而獲得長壽延年的效果。」[5] 這段文字分析了當時社會對「生」與「死」思想的探討，認為當時士人服食「五石散」最原始的目的是為了「長壽」，追求人生的永恆。然而，嵇康本人從未明確解釋過服散的目的，不過他在一篇題為《養生論》的文章中認為，「養生」不只是延年益壽、肉體生命的延長，還包括人生境界的提升：「善養生者則不然矣。清虛靜泰，少私寡欲。知名位之傷德，故忽而不營，非欲而強禁也。識厚味之害性，故棄而弗顧，非貪而後抑也。外物以累心不存，神氣以醇白獨著，曠然無憂患，寂然無思慮。又守之以一，養之以和，和理

2 嚴可均編：《全三國文》，卷四十七。
3 嚴可均編：《全三國文》，卷四十九。
4 金正耀：《道教與煉丹術論》（北京：宗教文化出版社，2001年），頁61。
5 容志毅：《中國煉丹術考略》（上海：三聯書店，1998年），頁41。

日濟，同乎大順。」[6] 意思是，養生還意味著忘卻塵憂。善於養生的人思想上淡泊虛無，行為上安靜然，不斷減去自己的私心和貪欲。名利地位那些外在的東西，會使人心性受到傷害所以不應留在心中，精神因為淳樸淡泊就能變得特別飽滿。飽受政治現實帶來的困擾，在嵇康的世界裡，服食「五石散」是其達到「清虛靜泰，少私寡欲」的生活狀態的手段之一，這也是在精神上得以超脫的方法。

嵇康追求自然個性，任情而為，通過奏樂、服散來安撫內心。從「藥」與「樂」這兩個其人生中重要部分的言行中，我們都可以看到其「避世」的處世哲學的影響。儘管其「避世」思想在後世多被賦予政治意義，但更深層面上，最終是一種對更高人生境界的追求。這種看境界和風骨，也造就了其異於俗約的行為，在世人所謂的「魏晉風度」中留下了濃墨重彩的一筆。

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6 嚴可均編：《全三國文》，卷四十七 。

To What Extent Do the Inaccurate Numbers in Herodotus Suggest a Political Motive?

Tiffany Zhang

The *Histories* by Herodotus describes the rise of the Persian Empire and discusses the causes and events of the Greco-Persian Wars between the Achaemenid Empire and the Greek city-states during the 5th century BCE. Recognized by modern historians as the 'Father of History', Herodotus pioneered the methodology of research and inquiry that was adopted for historical investigations in following centuries, including the use of interviews, travelling and examination of evidence. In the *Histories*, Herodotus makes frequent use of numbers, many of which are believed by modern historians to have been inflated. While it can be argued that the flawed numbers are the result of Herodotus' careless calculations or use of unreliable sources, a closer analysis of the historian's purpose of writing, as well as the effect of inflating these numbers, reveals that the inaccuracies are to a large extent products meticulously fabricated, thus suggesting a political motive. Simply put, Herodotus aimed at constructing a better image of the Greeks for future generations to commemorate.

Among modern historians, there has been a growing skepticism of the numeric details provided by Herodotus, in particular the size of Xerxes's army and the number of casualties at the battle of Marathon. He writes: "The number, then, of those whom Xerxes son of Darius led as far as the Sepiad headland and Thermopylae was five million, two hundred and eighty-three thousand, two hundred and twenty" (7.186). No modern scholar agrees with Herodotus' calculation that Xerxes brought a total of over five million men with him to Greece in 480BCE. The number, as Rubincam suggests, is "impossibly huge" (9) and "by no means generally accepted" (4). In addition, the description that "about six thousand four hundred men of the foreigners were killed" (*Histories* 6.118) compared to "one hundred and ninety-two Athenians" is "equally one-sided" (Marsh 35). It is beyond doubt that the numbers suggested by Herodotus are inaccurate.

There are three plausible explanations as to why the numbers may have been inflated: simple calculation errors; Herodotus' lack of access to reliable sources; or a deliberate attempt to fulfill his political motive by contorting the numbers. The first explanation is Herodotus' incompetence in computations. Herodotus often performs calculations in his works. Some believe his ability to calculate is "elementary" (Keyser 3) where he is only able to deal with the simplest and most basic principles of mathematics, performing few subtractions or divisions. In fact, calculation mistakes are not absent in his works, such as a division error in 7.187, where Herodotus calculates the corn consumed by Xerxes's army of 5,283,200, based on the fact that the whole army takes in one choenix per day (Keyser 7). These miscalculations are classified as "confusions in cross-referenced sums and a reluctance to work with fractions" (13). Moreover, Herodotus is known for having a higher tolerance for approximations and inaccuracies in his work, stemming from his "much lower rate of qualification" (Rubincam 8) as opposed to other historians. However, at the same time, Keyser (3) claims that Herodotus was not ignorant or careless in mathematics. "Of thirty-two calculations, "all [were] correct" (3), he challenges. The calculations of the size of Xerxes' triremes, the Greek fleet at Artemisium, and the Greek army at Plataea were all performed correctly, casting doubts as to whether the figure of five million Persian men was an unintentional error in the first place.

At the same time, some historians maintain that Herodotus' use of unreliable sources may have been the reason for the incorrect numbers. According to Asheri, Herodotus was a "researcher of oral traditions" (388). These sources, as Alan B. Lloyd describes, are considered "inadequate" (4) and could have generated false information, resulting in erroneous numbers. This argument, however, is refuted by John A. Scott, who believes that Herodotus, who was born under the Persian rule, did have access to reliable sources. Herodotus "had friends who had been members of the Persian as well as the Greek armies, and he traveled as widely in Persia as in Greece" (4), he states. This leaves us with only the last option: Herodotus purposefully distorted the numbers.

Herodotus, being an Athenian, is likely to have deliberately increased the numbers of the Persian army and exaggerated the difference in casualties between the two sides due to his own personal pro-Greek bias. It is highly possible that he did so to create a more positive image of the Greek warriors for future generations to honor and admire. Firstly, enlarging the size of the Persian army, whom the Greeks eventually defeated, sheds a positive light on the Greeks. It "[promotes] Greek bravery and determination, a testament to [Herodotus'] positive view of Greek culture and military prowess" (Freewalt 4). Several historians are in support of this view. They insist that Herodotus "could not have been deceived" (Scott 3) and intended to "propagate an untruth" (3), accusing the ancient historian of substantial fabrication of evidence. In addition, the numerical inferiority in casualties, as mentioned by Roberts, "[throws] the Greek victory more sharply into relief" (103). It "[conceals] one's own losses and [magnifies] those of one's enemy" (Hammond 4).

A glimpse of Herodotus' prologue in Book I supplies some insight into his purpose of writing the *Histories*. In his prologue, Herodotus records that he is writing the *Histories* "so that things done by man not be forgotten in time", and that the great achievements of the Greeks "do not lose their glory" (1.1). Thus, one could argue that Herodotus inflated the number of men in the Persian army, as well as the number of Persian casualties to alter history and portray the Greeks as more powerful and more courageous warriors than they were, wishing that Greeks could thereby be perceived more respectfully by their descendants or people of other ethnicities- clearly illustrating a political motive.

Herodotus' political motive of promoting the Greeks can also be seen in other episodes in the *Histories*. For instance, in 8.121, Herodotus discusses the aftermath of the battle of Salamis and King Xerxes's reaction to the Persian loss, where he alludes to the Persian king's cowardice by proclaiming that his building of a causeway between the mainland and Salamis was just a cover-up for the preparations of his flight. However, there is no evidence other than Herodotus' account suggesting that this is true. Therefore, it is assumed by modern historians to be a biased speculation formulated by Herodotus himself. This being the case, it seems probable that Herodotus' inflation of numbers was also due to his political motive.

In summary, although Herodotus was one of the first ancient historians to discard traditional mythology and invent the genre of historical investigations and is thus respected among scholars, problems concerning historical accuracy have also been noted. The numbers he includes in his work, in particular the size of the army of Xerxes and the number of casualties during the battle of Marathon, undoubtedly flawed. While some trust that the inaccurate numbers are unintentional calculation errors or the results of using unreliable sources, most modern historians now argue otherwise: strongly believing that Herodotus willfully concocted the numbers to cause the Greeks to appear in a more favorable light. Having studied Herodotus' prologue in Book I, a range of historical literature around this topic, as well as the effect of inflating these numbers, it is evident that the inaccurate numbers in Herodotus suggest to a large extent a pro-Greek political motive.

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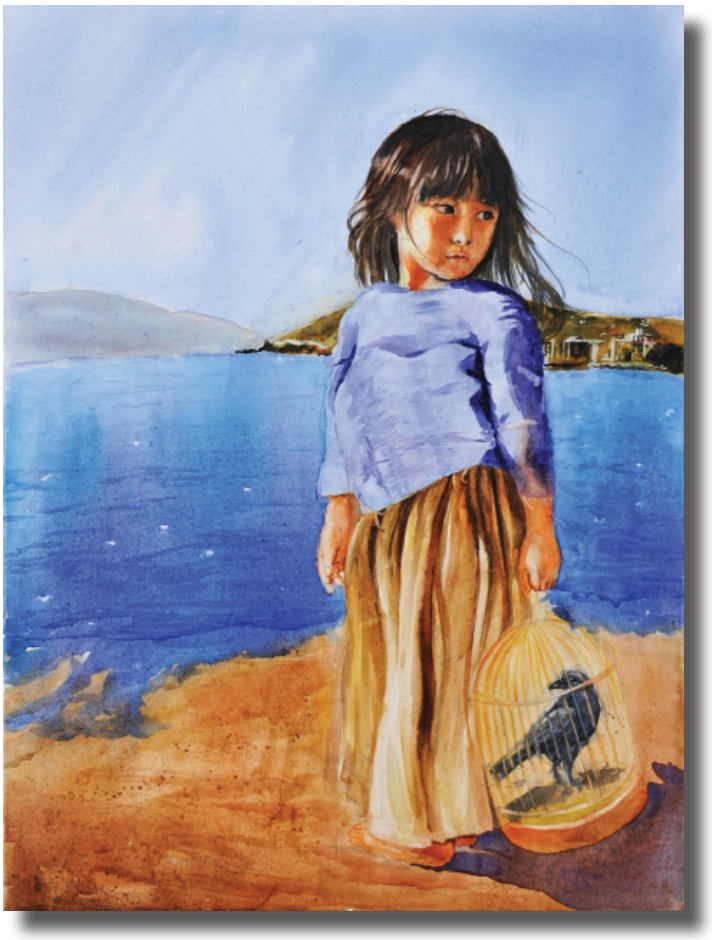


弘立書院同學藝術創作　2　　***The Cage***　by Muting Zhu

弘立書院同學藝術創作　3　　***Village by the Water***　　by Flora Ng

弘立書院同學藝術創作　4　　***Old General Post Office***　　by Vanessa Chung

How quickly and realistically can an algorithm generate an island landscape with diverse biomes for computer games?

Henry Mao

Abstract

Game developers are now able to take advantage of terrain generation algorithms that efficiently create diverse landscapes for computer games. These algorithms can generate a wide variety of new landscapes and worlds every time a game is played, thus creating unique gaming experiences and increasing replay value. Due to terrain generation algorithm's significance, this study explores *how quickly and realistically can an algorithm generate an island landscape with diverse biomes for computer games*.

Noise and fractal algorithms, such as the Perlin noise and Diamond Square algorithm, are explored to understand the recursive nature and fulfill the pseudorandom requirements of natural landscapes. Through the synthesis and control of these algorithms by seeding values, heightmaps are generated to model an island's geographical features and coastal landscape. Seeding methods include modeling the height of an island to be higher as it approaches the center of the land. Smooth gradients are then created by coherent noise to simulate granular landscape structures. Furthermore, Perlin noise is also used to determine moisture and temperature and hence classify areas of the island with specific biomes. These biomes are painted with textures and decorated with an obstacle generation algorithm to create trees and grassland. The result of the synthesized algorithm creates aesthetically pleasing islands that have potential use in games.

Experiments on heightmap using a square based grid shows a power relationship between terrain size and execution time. Although execution time is reasonable in context, power relationship suggests that large terrain may suffer from slow execution time.

The study concludes that realistically an island with diverse biomes can be generated quickly through the combined use of various algorithms and modifiers. However, limitations of such algorithms depend on the specific gameplay requirements and computation resources, which may hinder other types of landscape more complex than an island.

Introduction

Terrain generation algorithms refer to procedures that generate virtual landscapes. These algorithms have been increasingly important in the gaming industry ever since the release of the viral sandbox game *Minecraft*. *Minecraft's* terrain generation has been one of the key reasons for the game's success. Several other games, such as *Ace of Spades* and *Cube World*, have also implemented generated terrains to provide new and unique gaming experiences each time the game is played. In opposition to having developers create virtual worlds manually, terrain generation algorithms automatically create virtual worlds. This results in every game having a different playing experience and thus increases the replay value of the game. Proper implementation of this technology can increase sales of games and benefit the gaming industry.

Due to terrain generation algorithm's significance, this study will focus on:

"How quickly and realistically can an algorithm generate an island landscape with diverse biomes for computer games?"

The specific type of landscape "island" is chosen as it narrows the scope of exploration, but the concepts explored should apply to other types of landscapes.

Method

To answer this research question, an algorithm that generates and renders realistic 3D island landscapes will first be formulated and then its execution time will be profiled. General traits of an island must be apparent – a land mass with high elevation near the center should be surrounded by ocean similar to Figure 1.

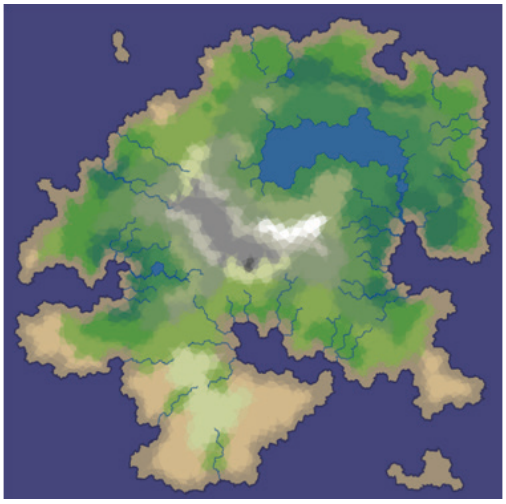


Figure 1 - An island
(Patel, "Polygonal Map Generation for Games")

Because the algorithm targets computer games, it must demonstrate the ability to affect gameplay mechanics. For example, biomes are an important part of creating diverse gameplay mechanics. A strategy game could employ a tundra biome where characters in-game walk slower compared to a desert biome, therefore adding extra depth to gameplay. Temperature could be a floating point variable that is multiplied with the movement speed of characters in-game to control their movement based on biomes. Biomes will also greatly affect how the terrain should be textured, as well as where trees and obstacles will be placed.

Thus, the island generated must contain a variety of different terrain biome types such as desert, tundra and rainforest. Furthermore, trees will be generated on the island to show that the algorithm is capable of creating obstacles. The algorithm will also use a coordinate system to make path finding operations easier. Lastly, the speed of the algorithm will be evaluated by profiling CPU execution time against terrain size and comparing it to the load time of popular games.

Due to the specific criteria for generating an island, I plan to investigate the following:

1. Grid systems;
2. Heightmaps;
3. Randomness and noise functions;
4. Decoration and obstacles of a terrain;
5. Biomes generation.

The algorithm will be written in the language C# and use the Unity 3D game engine to produce graphical renderings.

Investigation

Grids

The core concept behind many map based games such as *Civilization*, *Minecraft* and *StarCraft* is a grid system.

"Grids are built from a repetition of simple shapes" (Patel, "Amit's Thoughts on Grids") with each shape representing an area where gameplay occurs. In terrain generation, a coordinate in a grid represents the properties of the terrain at that point, such as the elevation and biome data.

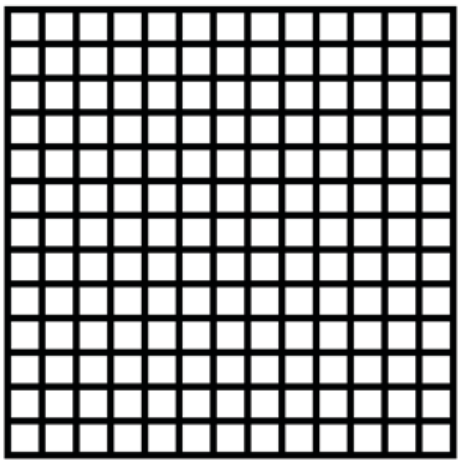


Figure 2 - A square grid

Using grids, divide an analogue landscape into digital format where data can easily be stored in a 2D array. Furthermore, grids have adjacency and can be converted into graph structures for path finding, which is especially useful in games.

Popular shapes for grids include squares (*Warcraft*), hexagons (*Civilization*) and triangles. For my algorithm, square grids (Figure 2) will be used as they "are the most common grids used in games, primarily because they are easy to use" (Patel, "Amit's Thoughts on Grids"). Points in a square grid can be described using Cartesian coordinates.

The Heightmap

A *heightmap* is a 2D array with points each representing the elevation of the terrain on a grid. The indices of the 2D array represent the x and y coordinates while the values of the array represent the height. Hence, a 3D terrain uses a 2D heightmap. A heightmap defines the shape of the terrain and can be generated using fractal algorithms and noise functions.

Noise and Randomness

Natural systems in real life seem random. Hence, in order to generate natural landscape, randomness must be used. This randomness is called *noise* - "a set of random numbers, usually arranged in a line or grid" (Patel, "Noise Functions and Map Generation").

A *uniform noise* function produces uniform randomness by returning each possible value with equal probability (Patel, "Noise Functions and Map Generation"). However, uniform randomness is not useful for generating terrains because it cannot be controlled to model the shape of a landscape. Shiffman states that "defaulting to randomness is not a particularly thoughtful solution to a design problem – in particular, the kind of problem that involves creating an organic or natural-looking simulation" (Shiffman 7).

Conversely, *non-uniform randomness* produces values that are not equal in occurrence and controlled to create a desired output (Patel, "Noise Functions and Map Generation"). For example, terrain elevation at one point depends on elevations of its adjacent points. A mountain rarely drops to an elevation located at sea level; it is more gradual. Hence, a mountain has a higher chance of sloping gradually than suddenly. The probability of height at one point depends on adjacent points. Therefore, it is non-uniform randomness.

Smooth change between two adjacent points is also classified as *coherent noise* where "for any two points in the space, the value of the noise function changes smoothly as you move from one point to the other" (Zucker). The coherence of noise can be described by a color. A rougher noise is blue while a smoother noise is red. The key in terrain generation is to search for the optimal smoothness that models terrain in real life.

Color of Noises (Types of smoothness)

Name	Smoothness	Notes
Red Noise	Very smooth	Created by averaging adjacent points
Pink Noise	Slightly smooth	Ideal for landscapes
White Noise	Neutral	Uniform randomness
Blue Noise	Slightly rough	Ideal for generating objects in a map such as trees and rocks
Violet Noise	Very rough	Created by the difference of adjacent points

Table 1 - Color of noises adapted from Patel, "Noise Functions and Map Generation"

A noise can also be periodic and controlled by its frequency (the repetition) and amplitude (Patel, "Noise Functions and Map Generation"). Perlin noise is an example of noise with periodic attributes.

Perlin Noise Algorithm

Perlin noise is an award winning algorithm for "generating coherent noise over a space" (Zucker). It is a multi-purpose coherent noise that "can be used to generate various effects with natural qualities, such as clouds, landscapes" (Shiffman 17) and patterns. The Perlin function takes two arguments and returns a float between -1 and 1 (Figure 3 and Figure 4).

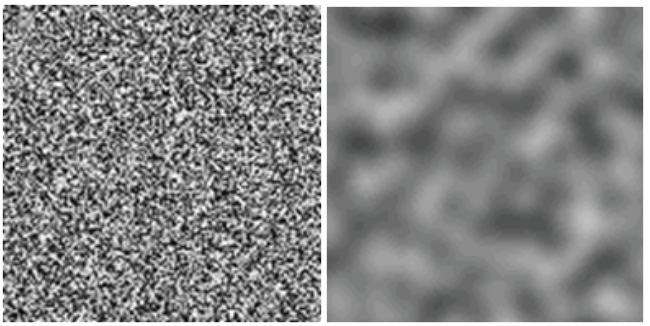


Figure 3 - Uniform Noise (left) vs Perlin Noise (right)

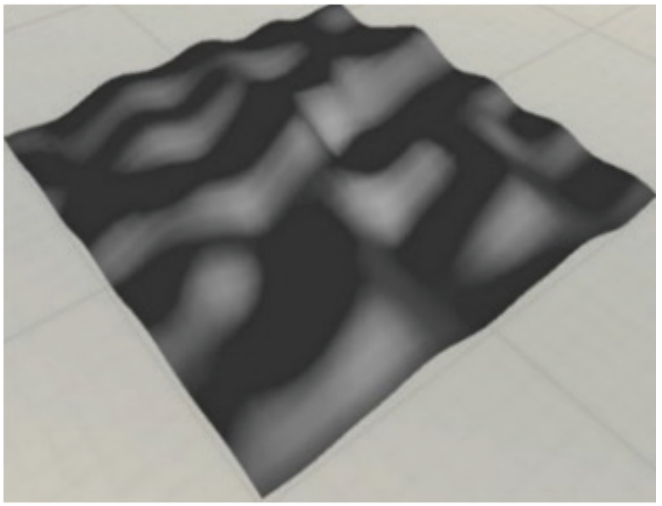


Figure 4 - A 3D visualization of Perlin noise

Octave

Perlin noise is created through summations of different frequency noise functions (Tulleken). Each summation is called an *octave*. The following is an example of a 6th octave Perlin noise.

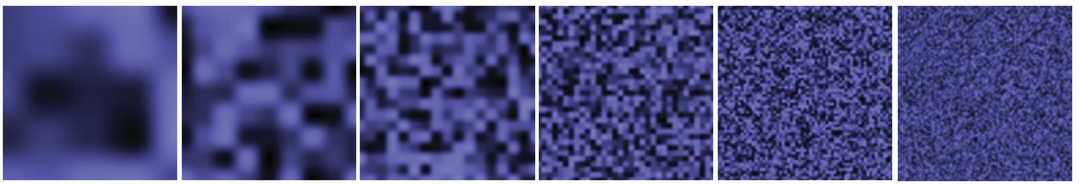


Figure 5 - Six different noise functions

Adding all these functions together produces the Perlin noise.

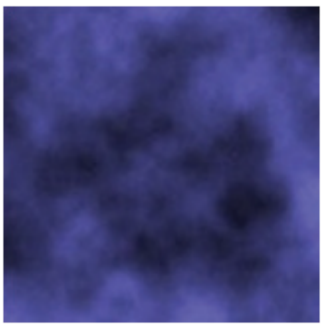


Figure 6 - Octave Summation (Tulleken)

As shown in Figure 6, Perlin noise mixes several octaves of noise together to generate the final noise.

Persistence

Persistence is a value (between 0 and 1) used to determine the amount of decrease in amplitude per successive octave (Bevins). High persistence creates rougher noise while low persistence creates smoother noise (Figure 7). An example of how amplitude correlates to persistence is $amplitude=persistence^{n}$, where **n** is the octave being generated. Hence, for a value between 0 and 1, the higher the octave, the lower amplitude.

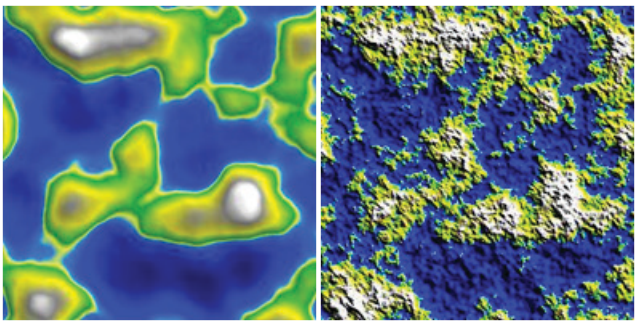


Figure 7 - Low persistence on left vs. high persistence on right (Bevins)

Perlin noise is not limited to heightmap generation; it can also be used for other aspects of terrain generation. The advantage of Perlin noise is that it is a function with two arguments and can be called without any other pre-processing required; it is simple and concise.

Fractals

A *fractal* was coined by mathematician Mandelbrot and defined as "a rough or fragmented geometric shape that can be split into parts, each of which is a reduced-size copy of the whole" (Shiffman 356).

Natural landscape consists of repetition that can be described using fractals because "the jagged edge of a broken rock in the palm of your hand has the same irregularities as a ridgeline on a distant horizon" (Martz). Hence, terrains can be described by considering a fractal algorithm.

The self-similarity (Shiffman 356) nature of landscapes implies that a terrain algorithm can be simplified into a recursive function that infinitely generates details of the terrain as required. Hence, "fractals all have a recursive definition" (Shiffman 358). A recursive function can be called more often to create more detailed landscapes.

Diamond Square Algorithm

One of the most popular fractal algorithms used for terrain generation is the *Diamond Square algorithm*. Its elegance emerges from its simplicity and its ability to generate a wide variety of fractal landscapes (Figure 8).

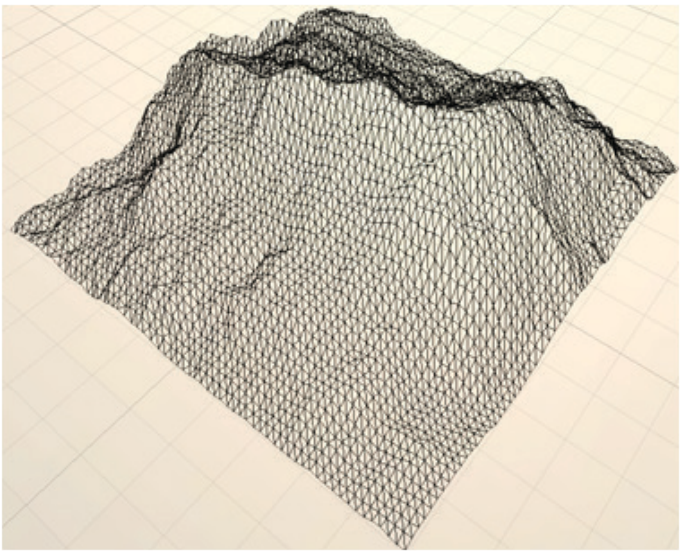


Figure 8 - Terrain generated with the Diamond Square algorithm

The Diamond Square algorithm uses a 2D array of dimension 2^n+1. This 2D array geometrically forms a square grid, with each point consisting a value representing the height of the terrain at that point. For my terrain heightmap, I set this value as a floating point value between 0 (lowest elevation) and 1 (highest elevation). This heightmap can then be used to render a 3D terrain.

The following example uses a simple 5x5 dimension array to demonstrate the Diamond Square algorithm. Figure 9 is a graphical representation of this array.

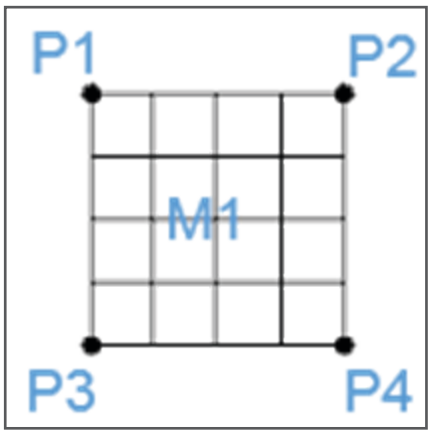


Figure 9 - Initial heightmap

Before running the algorithm, the program must manually set the corners of the square. This is called *seeding*. Each of the four corners (P1, P2, P3 and P4 from Figure 9) in the square are set to a random value between 0 and 1.

After seeding, the program proceeds to the Diamond Square algorithm. The Diamond Square algorithm consists of two steps: diamond and square. Each step computes midpoints based on corner heights, adds a small random factor to the elevation, then populates the heightmap. Hence, the Diamond Square algorithm is also called the *midpoint displacement algorithm* because it first calculates the midpoint, creating a smooth average slope (a type of red noise), then displaces it by adding a random variation.

Random variation is the range of possible random numbers that the midpoint may be displaced by. For example, my initial random variation ranges from -0.5 to 0.5. This means every height calculation adds a random value from -0.5 to 0.5. Random variation controls the roughness of the terrain similar to how persistence controls roughness in Perlin noise. The higher the random variation, the rougher the terrain.

Step 1: Diamond Step

Take the height values of the four corners (P1, P2, P3 and P4 from Figure 10) from the square and average the values. The center midpoint (M1 from Figure 10) of the array is then set as the average calculated. A random value is added to create variation.

$$m_1=(p_1+p_2+p_3+p_4)/4 + \text{random variation}$$

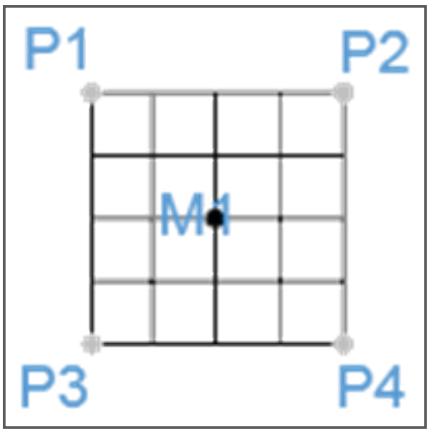


Figure 10 - Diamond step

Step 2: Square Step

Compute the four edge points of the square (E1, E2, E3 and E4 from Figure 11) by averaging the corner values of the corresponding edge adjacent to the edge point. A random value is added to create variation.

$$e_1=(p_1+p_2)/2 + \text{random variation}$$

$$e_2=(p_2+p_4)/2 + \text{random variation}$$

$$e_3=(p_3+p_4)/2 + \text{random variation}$$

$$e_4=(p_1+p_3)/2 + \text{random variation}$$

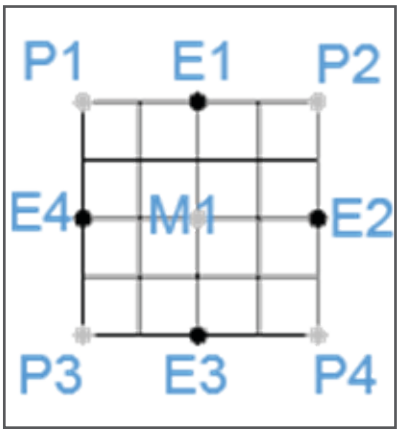


Figure 11- Square step

Step 3: Repeat

The first two steps compute sufficient information to subdivide the square into four smaller squares. As seen in Figure 11, P1, E1, E4 and M1 form a smaller square. The diamond and square steps can then be applied recursively to each of the four subdivided squares. In this recursion, however, the *random variation* is multiplied by a *variance reduction factor*. The variance reduction factor decreases the *random variation* as the recursive function accesses smaller subdivisions of the square. This causes the details on the terrain to be displaced less, creating smoothness.

The following is a 3D graphical representation of Diamond Square algorithm by Paul Boxley. As seen, the square is subdivided recursively to create fractal landscape.

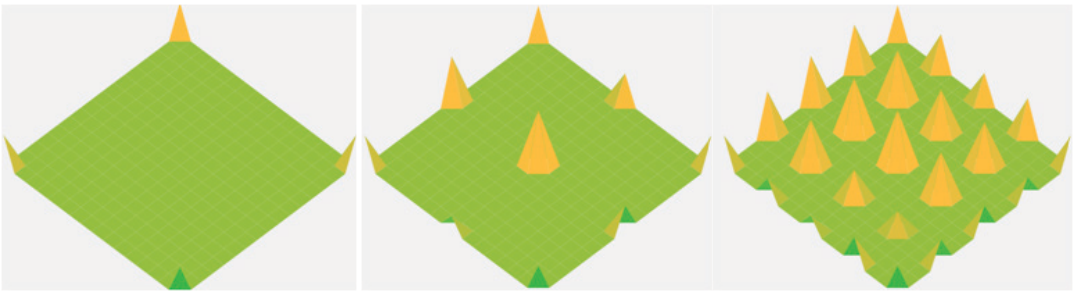


Figure 11 – Diamond Square algorithm

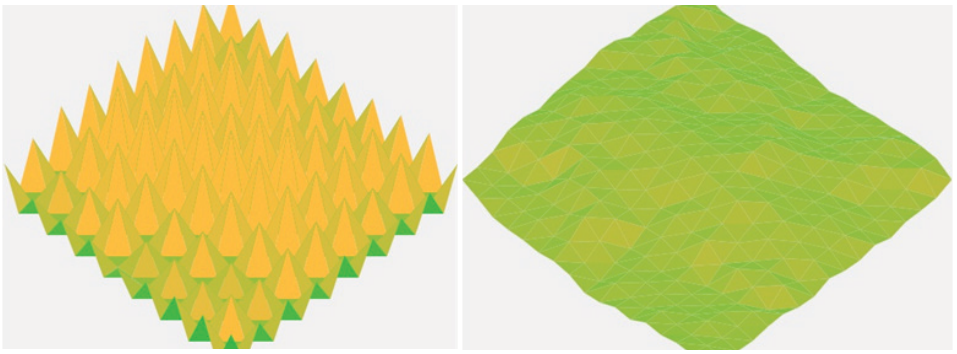


Figure 12 - Paul Boxley's Diamond Square visualization

Implementation

I implemented the Diamond Square algorithm and achieved favorable results:

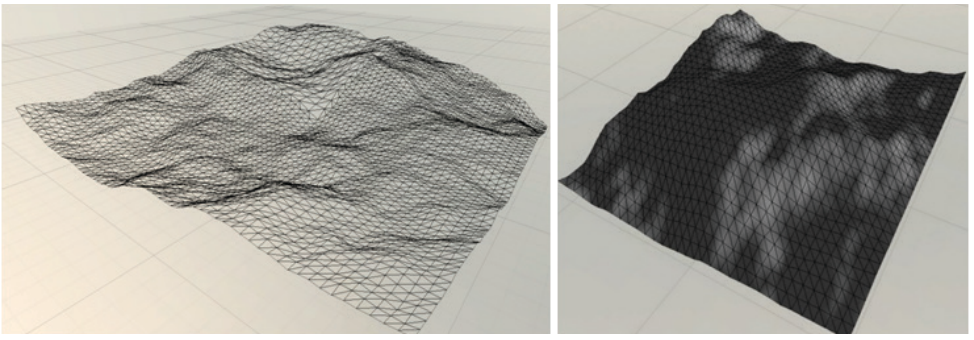


Figure 13 - Result of the Diamond Square algorithm

The Diamond Square algorithm seems to create smooth and realistic terrain. However, similar to any noise algorithm, it is difficult to achieve desired effects without post processing and seeding (Wiggill). One method to improve the algorithm is to seed values and add modifiers to provide more constraints in generation.

Seeding & Modifiers

Seeding values is the act of manually assigning heights at coordinates before the algorithm is run to control the fractal generation. To generate an island, I can seed values to ensure the edges of the map are low and the center is the highest (Game Development Stack Exchange).

I redesigned the initial seeding of the 2D array heightmap to better suit an island. Values around the edges of the square (Line 150) are set to zero (sea level elevation). The center of the heightmap is set to a random value greater than 0.4 (Line 152).

This array is then passed into the Diamond Square function (*GenerateDiamondSquare*) to generate the rest of the landscape based on the initial seeds. I applied a simple 3D texture render to better visualize the terrain.

Although the island looks decent, the shape is too square and the mountain is always at the center of the island; it is too predictable. To solve this, I took a different approach and used Perlin noise to first determine whether a point is either land or water and set the elevation to zero, then used Diamond Square to generate rest of the terrain. Perlin noise is better at creating smooth coastlines and hence fixes the problem of a square island (Patel, "Polygon Map Generation").

```
146         //Seed around the island, setting it to zero.
147         for (int x = 0; x < heightmap.GetLength(0); x++)
148             for (int y = 0; y < heightmap.GetLength(1); y++)
149                 if (x == 0 || y == 0 || x == size - 1 || y == size - 1)
150                     heightmap[x, y] = 0;
151
152         heightmap[size / 2, size / 2] = 0.4f + random.value * 0.4f;
153         GenerateDiamondSquare(0, 0, size, variance, heightmap);
154         heightmap = Smooth(heightmap);
```

Figure 14 - Island seeding code

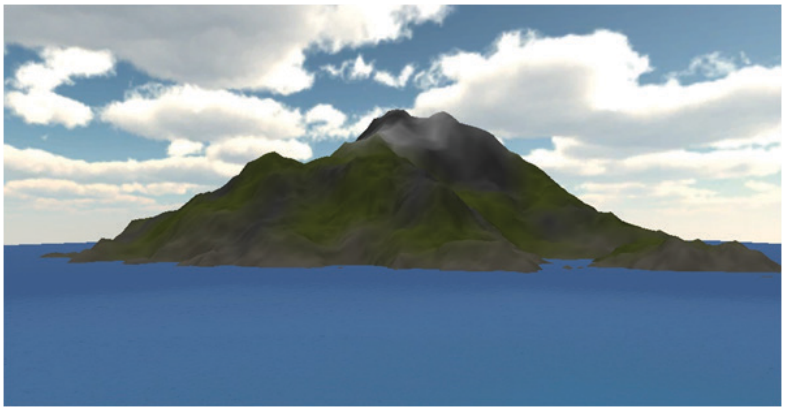


Figure 15 - Textured render of seeded terrain

The function "*IsLand*" (Figure 16) checks each point and marks it as land if Perlin noise returns a value greater than the percentage distance from the center squared (multiplied by a constant). This causes a higher chance to have land at the center of the map than at the border, forcing an island shape.

```
bool IsLand(Vector2 point)
{
    double c = perlin.GetValue(point.x, 0, point.y) * 0.5f + 0.5f;
    double distPerct = point.magnitude / size;
    return c > distPerct * distPerct * 0.3f + 0.3f;
}
```

Figure 16 – IsLand

I then created a function “MarkOcean” (Figure 17) to recursively set all connected water positions as ocean (zero elevation). The function is called from the border of the map and thus forces the points marked as water and connected to the border of the map to zero elevation. It ensures that the Diamond Square algorithm used to populate rest of the array later will not override what was first set by Perlin noise (Figure 18).

I then put these functions together and used the Diamond Square to generate rest of the landscape. In addition, I also used a power function to rescale the heights, removing unwanted square edges and further forcing the center to be higher.

```
/*
 * Marks points on the map as ocean. Start from the border of the map
 * and mark points that are water but not inside land as ocean.
 */
void MarkOcean()
{
    bool[,] marked = new bool[size, size];
    Queue<Point> markQueue = new Queue<Point>();

    grid.Where(p => p.isBorder).ForEach(p => markQueue.Enqueue(p));

    while (markQueue.Count > 0)
    {
        Point p = markQueue.Dequeue();

        if (!marked[p.x, p.y])
        {
            marked[p.x, p.y] = true;
            p.type = PointType.Ocean;
            p.elevation = 0;

            foreach (Point adj in p.GetAdjacent())
                if (adj.type == PointType.Water && adj.elevation != 0)
                    markQueue.Enqueue(adj);
        }
    }
}
```

Figure 17 - MarkOcean

```
public void Generate()
{
    //Sets up the seed values
    SetSeed();

    //Set each point as either land or water based on Perlin noise
    grid.Where(p =>!IsLand(new Vector2(p.x - size / 2, p.y - size / 2))).ForEach(p=>p.type =
      PointType.Water);

    MarkOcean();

    //Generate the landscape with Diamond Square algorithm
    GenerateDiamondSquare(0, 0, size, variance);

    //Use a cubic function to rescale the island, causing the edges to gradually decrease
    grid.ForEach(p => p.elevation = Mathf.Clamp01(p.elevation * 0.3f + p.elevation * Mathf.Pow(1 -
       new Vector2(p.x - size / 2, p.y - size / 2).magnitude / size, 2) * 0.7f));

    ApplyHeightmap();
}
```

Figure 18 - Perlin Noise

Results

I followed seeding conventions and used a random positive integer from 0 to 2,147,483,647 (max of 32-bit integer) to create random heightmaps.

Results conclude that islands generated are random with sufficient amount of variation for gameplay. Some islands generated had large chunks of land mass, while others were sparse with many lakes. This demonstrates that my algorithm is capable of generating variety. Games could take advantage of this variety by spawning monsters near lakes or zombies in high elevation locations.

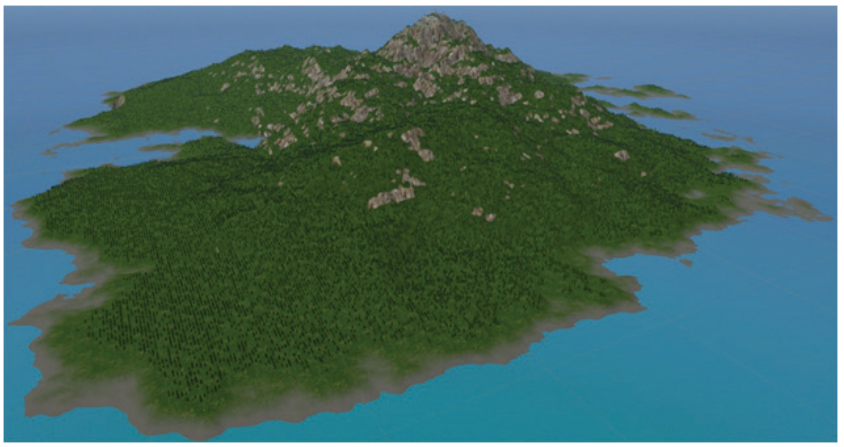
Seed Value	Result
1636969984	
1742426231	
1742426231	
1742426231	
108487534	

Table 2 - Heightmap seed results

Efficiency

Terrain Size

I experimented with terrain of different array sizes (the greater the array size, the larger the map) and resulted in the following data.

Terrain Width/w	Computation Time/t (s)					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
129	0.06026	0.05289	0.21342	0.05393	0.05431	0.08696
257	0.19054	0.19559	0.20045	0.19748	0.19824	0.19646
513	0.70548	0.75766	0.76669	0.82448	0.84955	0.78077
1025	3.21899	3.21899	3.13967	3.17758	3.44456	3.23995

Table 3 - Heightmap execution time data

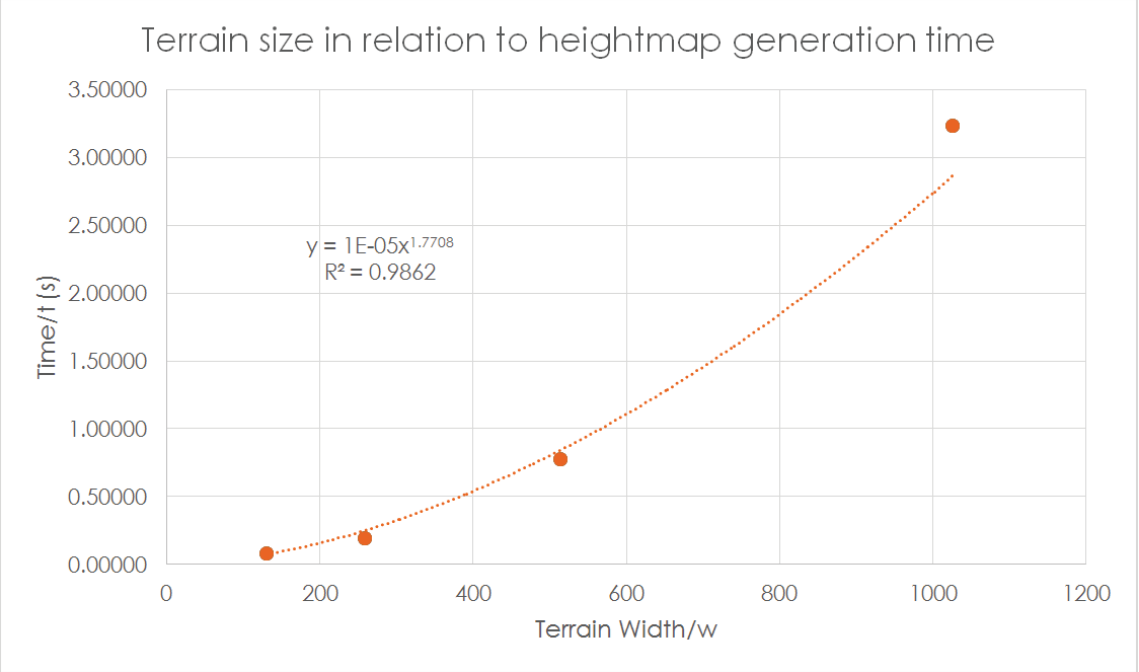


Figure 19 - Heightmap execution time graph

Based on experimental data, terrain size and execution time are approximately correlated with a power function. Hence, the Diamond Square algorithm has a run time of $O(n^{1.7708})$ for n terrain width. This may be due to the area of the terrain increasing with the terrain width in a squared relation.

The game *Minecraft* uses approximately 23.82 seconds to generate its terrain. It is important to note that *Minecraft*'s load time accounts for more than just its terrain, but its 100 million registered users demonstrate that the majority of players are willing to be patient for that amount of time (Makuch). Therefore, my terrain execution time is reasonable in context. Furthermore, the terrain is cached into memory after generation and thus players will not notice lag during gameplay but only experience an initial load time. However, it is worth concerning larger heightmaps as execution time takes significantly longer as terrain width increases.

Recursion

I implemented the Diamond Square algorithm using a recursive rather than an iterative approach because the algorithm could potentially take advantage of multithreading. Each recursive call operates at one subdivision of the terrain and is independent of other subdivisions. Hence, these evaluations can run concurrently. Recursion avoids mutability, making it easier to perform concurrently. This may reduce execution time ("What features make the functional language better for parallel programming?").

Decorating Terrain

With the heightmap generated, I searched for algorithms to paint terrain texture and generate obstacles such as trees. This algorithm will be later modified to render biomes.

Painting

The painting algorithm I created is based on source code I found from the "Multi-Purpose Game Starter Kit". First, I prepared a set of textures consisting of slope surfaces, coastlines and flat land. Then, the algorithm paints areas of the terrain that have a steepness greater than 45 degrees with a rock texture and areas with less than 45 degrees with a grass texture. Areas near the ocean used a sand texture ("Multi-Purpose Game Starter Kit"). This algorithm is an approximation of reality and efficient in execution time; it is sufficient for gameplay.

Trees

Because trees tend to bunch close together and fits the definition of coherent noise, I used Perlin noise with a low frequency to compute the locations where trees could be placed. The steepness of the land is also checked to make sure trees are not placed on cliffs or rocky surfaces. This method can also apply to generating rocks and other obstacles, as seen in Figure 20 and Figure 21.

The result is a realistic looking island with trees and textures.

Figure 20 - Perlin Noise; Trees

Figure 21 - Perlin Noise; Island Steepness

Biome Generation

The game most famous for its procedural terrain generation and diverse biomes is *Minecraft*. *Minecraft* uses Perlin noise for terrain generation and contains a variety of biomes. The source code is available through the *Minecraft Mod Coder Pack*.

Minecraft structures its biome generation into an object oriented structure. *BiomeGenBase* is an abstract class extended by different biome classes, such as *BiomeGenPlains* for the plains biome and *BiomeGenTaiga* for the taiga biome. Each biome class overrides a terrain generation method that handles terrain generation for that specific biome. Hence, biomes can easily take advantage of polymorphism to specify its own generation algorithm.

Each biome has its own properties such as predominant color, temperature, moisture, and biome height data. As seen from the code (Figure 22), setters are used to change these values.

Moisture and Temperature

The approach I will use for biome generation is inspired by *Minecraft*.

First, I will define temperature and moisture (also called rainfall) - two variables that will determine what biome needs to be generated based on Figure 24. This creates a more realistic approach as deserts would never appear adjacent to tundra if the two variables change gradually. These two variables are a floating point value between zero and one; one being the maximum intensity of that climate trait (Figure 25).

```
private static final BiomeGenBase[] biomeList = new BiomeGenBase[256];
public static final Set explorationBiomesList = Sets.newHashSet();
public static final BiomeGenBase ocean = (new BiomeGenOcean(0)).setColor(112).setBiomeName("Ocean").setHeight(height_O
public static final BiomeGenBase plains = (new BiomeGenPlains(1)).setColor(9286496).setBiomeName("Plains");
public static final BiomeGenBase desert = (new BiomeGenDesert(2)).setColor(16421912).setBiomeName("Desert").setDisable
public static final BiomeGenBase extremeHills = (new BiomeGenHills(3, false)).setColor(6316128).setBiomeName("Extreme
public static final BiomeGenBase forest = (new BiomeGenForest(4, 0)).setColor(353825).setBiomeName("Forest");
public static final BiomeGenBase taiga = (new BiomeGenTaiga(5, 0)).setColor(747097).setBiomeName("Taiga").func_76733_a
public static final BiomeGenBase swampland = (new BiomeGenSwamp(6)).setColor(522674).setBiomeName("Swampland").func_76
public static final BiomeGenBase river = (new BiomeGenRiver(7)).setColor(255).setBiomeName("River").setHeight(height_S
public static final BiomeGenBase hell = (new BiomeGenHell(8)).setColor(16711680).setBiomeName("Hell").setDisableRain()
```

Figure 22 - Instantiation of static biome objects ("MCP Website - Mod Coder Pack Homepage")

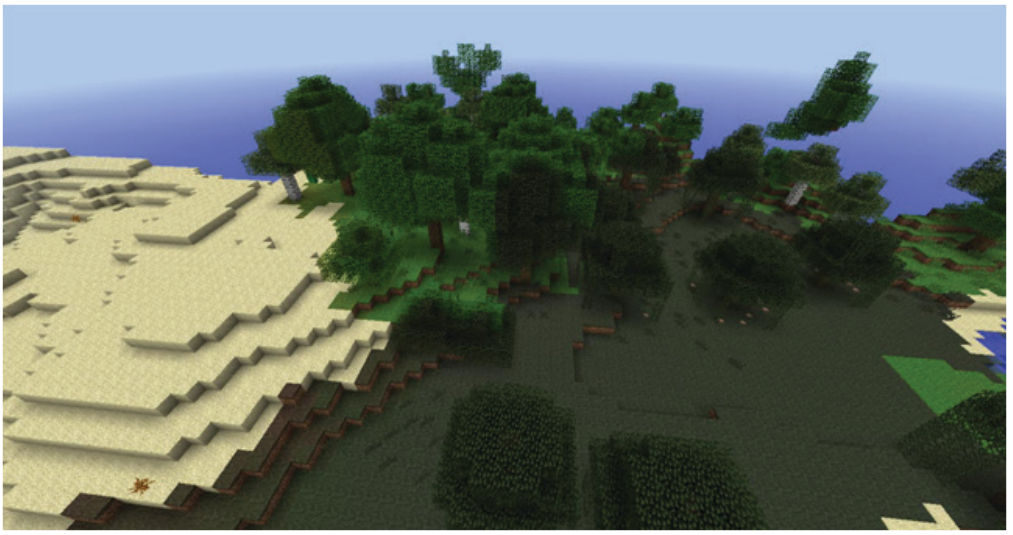


Figure 23 - A desert next to a swamp biome

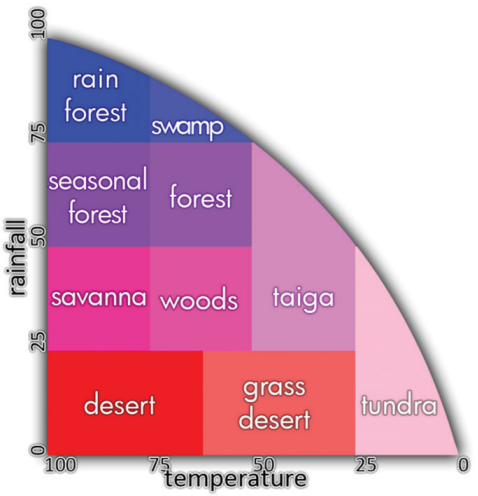


Figure 24 - A temperature vs moisture graph

```
public float GetDeviation(float temperature, float moisture)
{
    return Vector2.Distance(new Vector2(this.temperature, this.moisture), new
      Vector2(temperature, moisture));
}
```

Figure 25 - Float Point

Perlin noise is used to determine the temperature and moisture because it is coherent and thus provides smooth transitions between biomes (Figure 26).

Taking *Minecraft's* objected oriented approach, I wrote a biome class to treat each biome as an object. The biome class consists of temperature and moisture, and a virtual method to render textures. Following the diagram in Figure 24, I implemented five biomes: ocean, desert, tundra, savanna and rain forest.

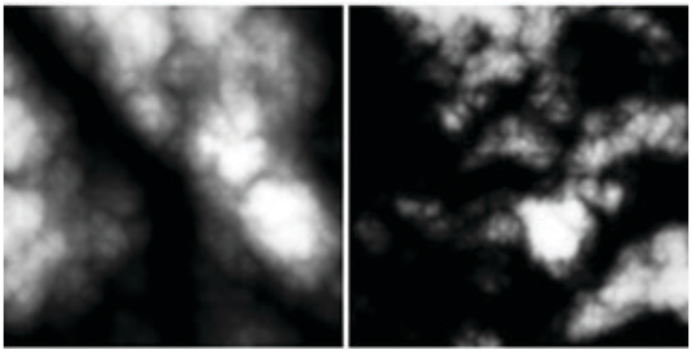


Figure 26 - Moisture (left) vs temperature (right) noise (Patel "Simple map generation")

Each point on the map will have their moisture and temperature assigned by Perlin noise. This is done by using the distance formula to calculate the closest biome from the given moisture and temperature.

Results

I generated five trials with different seed values and rendered the biomes with different texture colors and the results were satisfactory. However, there are harsh lines between biomes. These harsh lines can be reduced by texture blending or using fuzzy logic. Instead of setting points to discrete biome, they could be set with a floating point value to describe the extent to which it corresponds to a specific biome. This may allow biomes to blend better, but may require more execution time.

Efficiency

I profiled the efficiency of the biome generation algorithm in the following data.

Similar to the heightmap generation time, the biome generation algorithm has a run time of $O(n^{2.0044})$ for n terrain width. Biome generation takes more time than the heightmap. This may be due to the use of square roots (distance formula) and the increase use of Perlin noise. The results indicate that Perlin noise may be an expensive operation. The data is shown in Table 5 and Figure 27.

Conclusion

It is imperative to understand that terrain generation is not a simple sorting algorithm. Rather, it is a combination of various algorithms and seeding methods. Perlin noise is used to determine if a point is either land or water to create coastlines. Then, Diamond Square algorithm is used to generate the remaining landscape. Results from Table 2 show that this method resulted in visually pleasing aesthetics of an island. Most of the heightmap results consist of a high elevation center surrounded with low elevation ocean. The renderings also suggest that the algorithm generates a wide variety of different island shapes as shown in Table 2, where seed 1742426231 had a large mountain and seed 108487534 had a large lake in the center.

Biomes generated by the algorithm consist of five different types. Table 3 demonstrates that a wide variety of biomes can be generated while maintaining gradual biome transitions through the use of Perlin noise for temperature and moisture values. The object oriented approach in classifying biomes allows new biomes to be easily implemented.

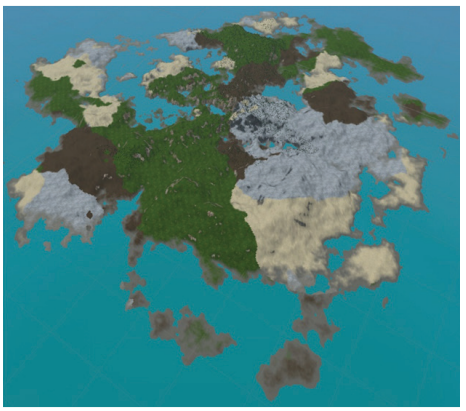
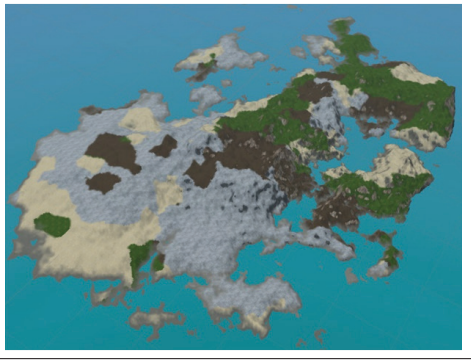
Seed Value	Result
182302972	
154988984	
2095045286	
1063449136	
1693702941	

Table 4 - Biome seed map

Terrain Width/w	Computation Time/t (s)					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
129	0.08972	0.08811	0.08811	0.09289	0.09279	0.09033
257	0.36693	0.35353	0.35145	0.36095	0.36557	0.35969
513	1.38901	1.38933	1.42850	1.45067	1.48225	1.42795
1025	5.80310	5.85986	5.83663	5.70507	5.63121	5.76717

Table 5 - Biome execution time data

As an algorithm made to target computer games, the grid system chosen allows path finding operations and random object placements. Trees are generated in the algorithm to demonstrate that objects can be easily placed on the landscape based on the terrain slope. This strategy may benefit games that want to generate secret treasure chests and other obstacles.

Terrain algorithms targeted towards games have limiting factors, such as design and balance. For example, some games desire a more discrete landscape rather than granular landscape to reduce complexity. These games will need to truncate their generated heightmap. Other games, such as strategy games, may require landscape to be fair for all players where terrain randomness is in contradiction to a balance design.

Repeated executions demonstrate that the synthesized algorithm has a reasonable execution time in comparison to other mainstream games, (my algorithm's 3.23995 load time verses *Minecraft's* 23.82 load time). Hence, within a gaming context, my algorithm is efficient and what an average user will be patient with. However, due to the power relationship between terrain width and execution time, large terrains may be suffer from longer load time.

Conclusively, this study shows that algorithms can definitely generate island landscape with diverse biomes quickly and realistically for computer games. The limitations of these algorithms depend on the gameplay mechanics and the terrain size. However, unresolved questions on terrain generation remains. How can this algorithm be applied to other types of landscapes? What is the limit in the terrain size given a reasonable execution time? How can algorithms generate other aspects of a terrain such as rivers and lakes? While terrain generation algorithms has its limitations and may not be suitable for all games, the rising trend of games implementing will definitely lead to new advancements in this area of computing and new dimensions of engaging gameplay experiences for players.

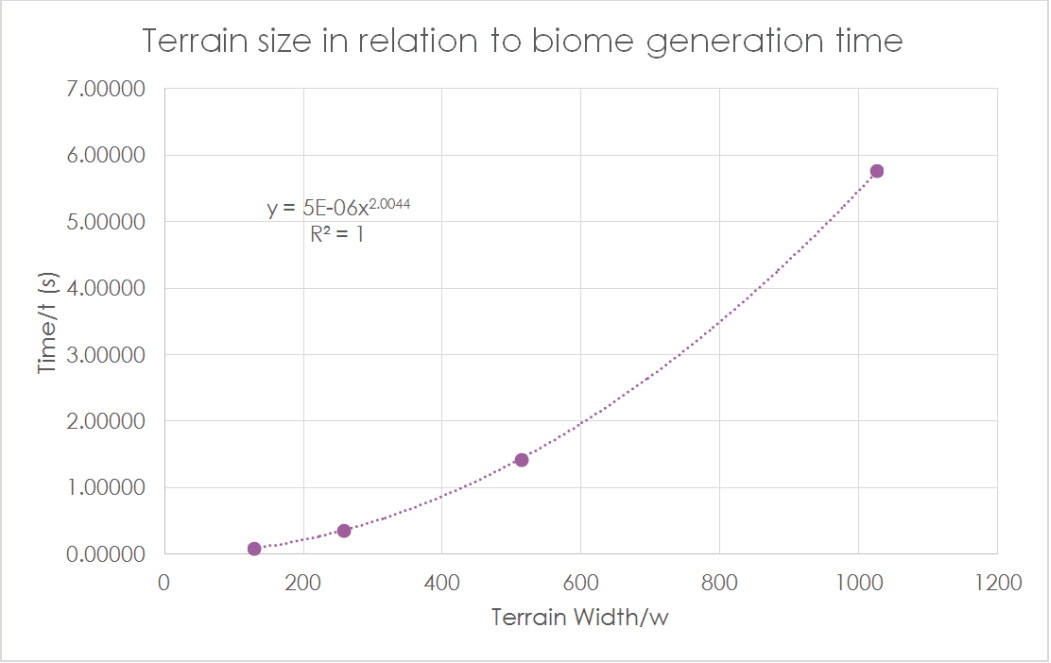


Figure 27 - Biome execution time graph

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What are the Characteristics of Gold(III) Chloride ($AuCl_3$) Speciation in Water Vapour and Steam?

Keith Kam

Abstract

Throughout history, gold has been a popular form of investment due to its stability compared to other types of investment (Katz). Apart from its use in monetary exchange, gold's unique properties make it valuable for electronics. Although gold has a higher resistivity at 20°C (2.21 μΩ.cm) than either silver or copper (1.68 and 1.59 μΩ.cm respectively) (Lide), gold is largely unreactive and its resistance to corrosion and tarnishing makes it valuable when reliability is a priority (Goodfellow).

In order to locate deposits of gold, the process of ore formation, or ore genesis, must first be understood. As water-rich fluids pass through large amounts of crust, trace amounts of metals are extracted and deposited in smaller volumes of rock under specific conditions, forming economically viable ore deposits (Heinrich 263). Thus the characterization of gold complexes is imperative to furthering the understanding of the precise chemical and physical processes that occur in the formation of gold deposits.

In this study, 50 $mmol.dm^{-3}$ gold chloride solution was analyzed with electrospray ionization (ESI) and Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS) in order to determine the possible complexes and their relative abundances. Computer simulations were subsequently used to determine the solubilities of each type of complex at given conditions. Five main groups of clusters have been identified, $AuCl_2(H_2O)_n$ (n=0-4), $AuCl(OH)(H_2O)_n$ (n=0-1), $AuCl_2(HCl)_2(H_2O)_n$ (n=0-4), $Au_2Cl_5(H_2O)_n$ (n=0-2), $Au_2Cl_4(OH)(H_2O)_n$ (n=0-3).

1. Introduction

In ancient China, gold was the royal colour and has since been associated with wealth and prosperity (Illuminant). Gold has been a common gift for occasions such as weddings, birthdays, and childbirth, and is commonly used as a way to store wealth (Popple). In recent years, investment in gold has surged due to its relative stability compared to other forms of investment (Katz). Furthermore, due to various political reasons, the Chinese government has been promoting investment in gold since 2009 (Popple). To meet the increasing demand of gold, the formation of gold deposits must first be understood so that gold mining and extraction process can be made more effective.

Hydrothermal deposits are formed from aqueous solutions rising through the crust after being heated by geothermal activity (Heinrich 263). Precipitation is caused by changes in temperature and pressure resulting in changing reaction free energies (Heinrich 263). At depths where these pressure-temperature conditions result in the precipitation of precious metals, one would gradually see the formation of economically relevant ore deposits of gold. Hence, Zhang *et al*. (133) list rock deformation, fluid flow, thermal transport and chemical reactions during mineralization, as the four key processes leading to ore formation. By understanding the modes of transport and stability of various gold species under these conditions, future predictions may be made with regard to the concentration or accumulation of economic gold deposits.

While metals may be transported and redistributed via both gas and liquid media, both phases have fundamentally different physical and chemical properties. Among these properties, fluid or vapour density due to hydrogen bonding plays an important role with regard to the affinity of precious metals such as gold to a solvent. In a fluid, hydrogen bonds are strong, resulting in a viscous fluid relative to a more mobile vapour phase. This plays an important role in the transport of gold in the earth's crust as it implies redistribution of precious metals may be primarily based on gas phase movement.

In hydrothermal fluids, water inhibits gold from aggregating and forming bulk solids, essentially dissolving gold. On the other hand, the interactions between gold atoms and water molecules in water vapour are stronger compared to those between gold and liquid water (Willliam-Jones *et al*. 228). Thus gold speciates differently in vapour than in liquid, forming molecular clusters. However, the processes these nano solids undergo to form bulk solids is largely unknown and requires knowledge of the structures and compositions of intermediate steps. One way to study these species is through a combination of experimental mass spectrometry data and theoretical modelling.

In this study, the speciation of gold in a simulated vapour phase was probed using ESI and FTICR to provide information about the composition of prenucleation clusters that might later be applied to more complex systems. These experiments can show how molecular water and ligands such as Cl^- interact with gold in low density aqueous systems, providing an insight into the stability, mobility and accumulation of hydrothermal gold ore deposits.

Gold is a valuable metal and understanding the formation of its ore is essential in locating economic metallic gold deposits. As gold is in the same periodic group as copper and silver, the results of this investigation may also be applicable to these two metals. For gold, the main deposit-forming liquid has been suggested to be magmatic gas condensate rather than magmatic brine of meteoric fluids (Baker and Andrew 810). As such, the scope of this study is limited to speciation of gold in water vapour and steam.

In ore-forming fluids, gold is most likely to have SH^-, Cl^- and OH^- as ligands (Stefánsson 29). While experimental results have shown sulfide complexes to be generally the most stable among the three, chloride complexation is equally important as it becomes more dominant in acidic conditions when sulfur complexes become less stable (Stefánsson 29). This leads to my research question: **What are the main cluster types present in gold chloride ($AuCl_3$) and water vapour/steam systems?**

I hypothesize that the since the sample is a solution, the presence of water as a ligand will be significant in many cluster types. Furthermore, I predict the presence of clusters such as $AuCl_2^+$ and $Au_2Cl_5^+$ since gold's most common oxidation state is 3 and these clusters would be +1 charged and thus easily detectable by the mass spectrometer.

2. Background

2.1 Complex Ions

Transition metals in solution have high charge density and are surrounded by ligands, molecules or ions that possess electron lone pairs (Brown and Ford 124). They then form dative covalent bonds, where both electrons in the covalent bond come from the ligand (Brown and Ford 157). In gold(III) chloride solution, gold is the central ion and ligands may include H_2O, HCl and Cl^-.

2.2 Electrospray ionization (ESI)

In order to analyze a sample using mass spectrometry, the sample must consist of gaseous ions. *Electrospray ionization* is a method used to create gaseous ions from a sample solution. The dilute analyte solution is first injected through a capillary needle, forming an aerosol (Murphy). The capillary needle is also kept at a very high voltage, placing a charge on the fine droplets in the spray (Murphy). Dry gas, heat and high vacuum can then be used to evaporate solvents, reducing the size of individual droplets until the analyte has completely entered the gas phase and is ready for the mass analyzer (Gregory).

Unlike the majority of ionization techniques, ESI is unique in that it can produce multiply charged ions (Gregory). This characteristic makes it valuable for the current study as it does not restrict the range of complexes that can be formed. Furthermore, the use of ESI extends the mass range of the analyzer to around 2000 amu, ensuring larger complexes with several gold atoms can also be detected (Gregory). However this also means that different charges have to be taken into account during the process of identifying complexes, in which the *m/z* simulation read-out is dependent on the charge chosen. For example, a complex with a mass of 50 daltons and a +2 charge would show up at the same *m/z* value on the mass spectrum as a species with with a mass of 25 daltons and +1 charge. In order to differentiate the two species or to determine the ratio of abundance, the intensity and location of other peaks in the respective simulations have to be compared.

Due to the structure of the apparatus, ESI equipment can be very difficult to clean (Murphy). As such, contamination from previous experiments may occur. In data sets, this would mean some peaks are not formed by complexes originating from the analyte solution. This problem can be ameliorated by obtaining a list of solutions the ESI apparatus has previously been used for, giving a list of possible peaks when there are unidentified peaks. For the apparatus used in this study, zinc chloride and zinc sulfate were previously analyzed and thus peaks corresponding to these chemicals can be ignored.

2.3 Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS)

FT-ICR is a method for determining the mass to charge ratio of gaseous ions. This method is based upon the characteristics of ion cyclotron movement. When an ion moves through a uniform magnetic field, it experiences a force perpendicular to the magnetic field and its motion, curving the path of the ion such that the ion moves in a circle (Marshall, *et al.* 2).

The movement of these particles can thus be modelled mathematically using knowledge of Lorentz forces and orbital motion. Several key relationships can thus be derived. Firstly, the radius of this circular path is proportional to momentum and period but inversely proportional to mass (Britannica School). Secondly, all ions of a given mass to charge ratio have the same orbital frequency (Marshall, *et al.* 2). Thus detecting the presence of orbital frequency can be used to deduce the presence of particles with certain mass to charge ratios.

In the classic cyclotron, moving charge consitituting a current flows through the middle while a magnetic field is maintained perpendicular to the direction of flow so that particles are deflected into a circular path (Britannica School). An electric field is controlled by an oscillator, changing the direction of the field so that particles can be accelerated every time they pass through (Britannica School).

The *Fourier transform method* consists of first accelerating all particles to their respective resonant frequencies. This is done by having the oscillator sweep through the frequencies (Gregory). As the moving particles have charges, they emit radiation with frequencies corresponding to their orbital frequencies. This radiation is recorded by the sensor panels and processed via a mathematical function called the Fourier transformation to create a frequency spectrum (Gregory). As frequency is proportional to the mass to charge ratio, a mass spectrograph can be created.

Of all mass analysis techniques, FT-ICR is known to have the highest resolution (Gregory). Furthermore, like ESI, FT-ICR is also suited for high mass analytes, making it a suitable choice for this study (Gregory).

2.4 Bruker Daltonics Data Analysis

In the current study, *Bruker Daltonics Data Analysis* is used to view the mass spectra of gold(III) chloride solution. Data Analysis also includes the tools to simulate a spectra based on chemical formula and charge. Through trial and error, the experimental peaks can be matched with a chemical species.

Bruker Daltonics Data Analysis is used primarily because the mass spectrometer is also from Bruker Daltonics. Using the same provider ensures there will not be any problems with reading the mass spectrometry files as there are many mass spectrometry file types currently available.

3. Method

3.1 Gold(III) Chloride Solution

Gold(III) chloride solutions were prepared with deionized water (Millipore). 1.9790 g of $AuCl_3$ was measured out using an analytical balance (±0.0001 g). The crystals were then washed into a 100.00 ± 0.01 mL volumetric flask. Deionized water was added until the meniscus reached the 100 mL mark.

3.2 Mass spectrometry

Mass spectrometry data was created using a Bruker Daltonics 7.0 Tesla Fourier transform ion cyclotron resonance mass spectrometer. A syringe was cleaned no less than five times with deionized water to minimize contamination from previous trials. The analyte solution was then taken up into the syringe and automatically dispensed into the ESI. A mass spectrum was then generated, as seen in Figure 1.

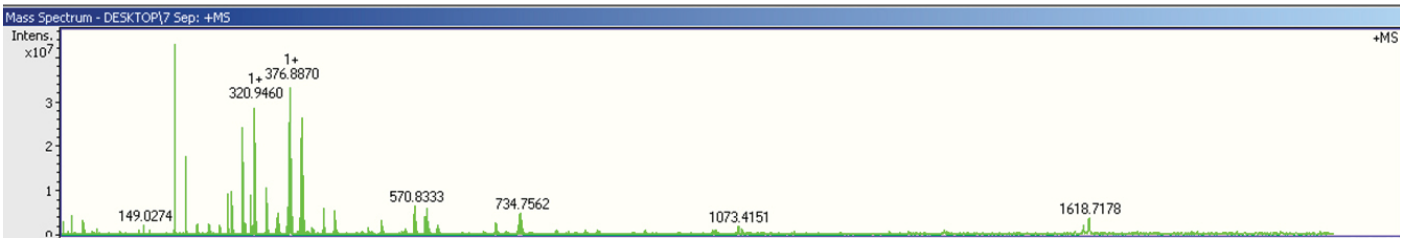


Fig. 1: Mass spectrum of 50 mM $AuCl_3$ (Mass charge ratio to intensity)

3.3 Identifying complexes

A mass spectrum is then simulated and viewed on *Bruker Daltonics Data Analysis*. Simulations of mass spectra were made by inputting the chemical formula with the charge number. It was found that that whether the charge inputted is positive or negative has no observable impact on the output. As such, to speed up the process of trying chemical formulae, a positive charge of +1 is used for the charge input. A mass spectrometry simulation can be considered to match with the data if the peaks are at the same *m/z* values and their relative abundances are the same. This is particularly useful for distinguishing between Cl and $(H_2O)OH$ (see Figure 2). Since Cl^+ and $(H_2O)OH^+$ both have a peak at 35.00±0.07 *m/z*, it is the presence of the second peak at 37 *m/z* that indicates the presence of Cl^+ rather than $(H_2O)OH^+$.

This principle can also be applied to complexes. Often a signal in the data would be formed by a mixture, where one species has Cl and the other $(H_2O)OH$. To determine the relative abundances of each, the ratio of peak heights of each simulation is first found. The concentration of each can then be found algebraically. This can be seen in the analysis of $Au_2Cl_5^+$ and $AuCl_4(OH)(H_2O)^+$, shown below in Figure 3.

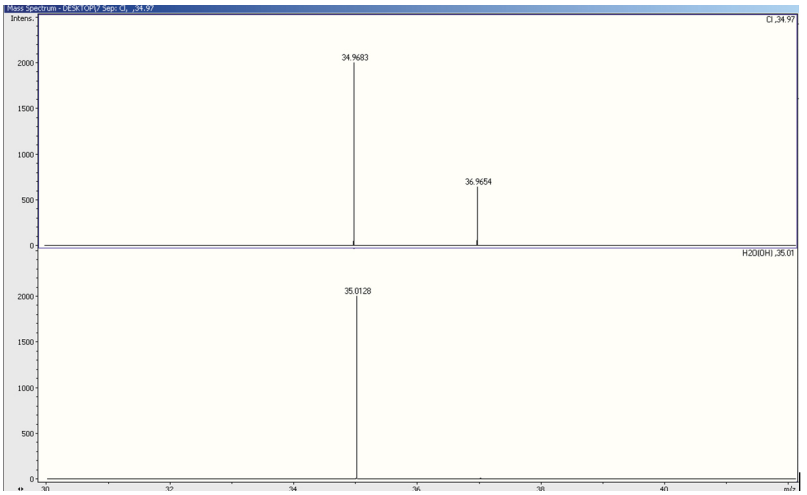


Fig. 2: Mass spectra simulation for Cl^+ (top) and $(H_2O)OH^+$ (bottom) (Mass charge ratio to intensity)

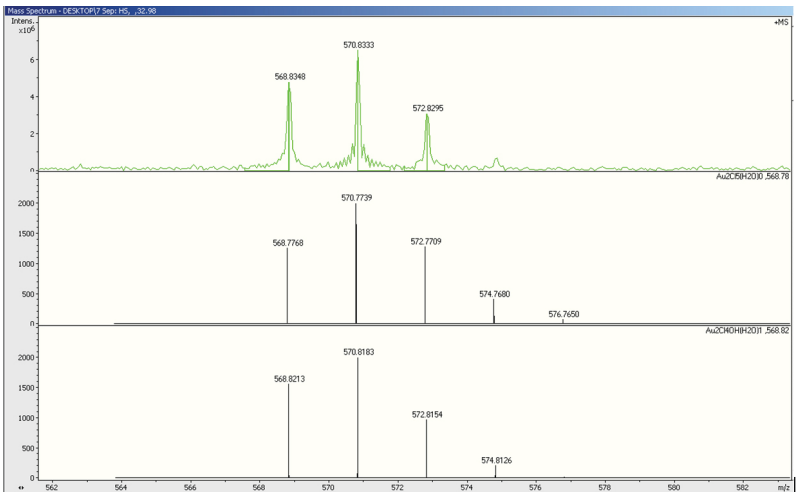


Fig. 3: Mass Spectrometry data, $Au_2Cl_5^+$, $Au_2Cl_4(OH)(H_2O)^+$ (Mass charge ratio to intensity)

The precise abundances of each peak can be found in Data Analysis by hovering over the peak. In the mass spectrometry data, the ratio of abundance of first peak and second peak in the data is *4754459/6495907≈0.732*. This was then done with the two simulations, giving 0.626 for $Au_2Cl_5^+$ and 0.780 for $Au_2Cl(OH)(H_2O)^+$. As the peak ratio in the raw data is between the two ratios given by the simulations, this indicates that the peak comprises a mixture of the two species. The expected ratio of the abundances of the two species can then be found algebraically:

Let the abundance of $Au_2Cl_5^+$ be x; then the abundance of $Au_2Cl(OH)(H_2O)^+ = (1 - x)$

peak ratio in data =

(ratio of $Au_2Cl_5^+$ x abundance) +
(ratio of $Au_2Cl(OH)(H_2O)^+$ x abundance)

$$0.732 = 0.626x + 0.780\,(1 - x)$$
$$0.732 = 0.626x + 0.780 - 0.780x$$
$$-0.048 = -0.154x$$
$$x = 0.312$$

Thus, 31.2% of the peak at 570 daltons consists of Au_2Cl_5, while the remaining 68.8% consists of $Au_2Cl(OH)(H_2O)$.

Another method to accelerate the species identifying process is through the use of the annotation tool of Data Analysis. This tool displays the difference in *m/z* between selected peaks, as seen in Figure 4. If one of the peaks has been previously identified and the difference between the *m/z* of the two peaks is a molecular or atomic mass that corresponds to an atom of an element or a common group, the new peak can be quickly identified by adding or subtracting the element or group.

For example, the peak of 302 was previously identified to be $AuCl_2(H_2O)_2$. As the difference to the next peak of 320 is 18, the molecular mass of water, an educated guess is that the subsequent peak has an additional water molecule. This guess can then be confirmed by matching it with another mass spectrometry simulation.

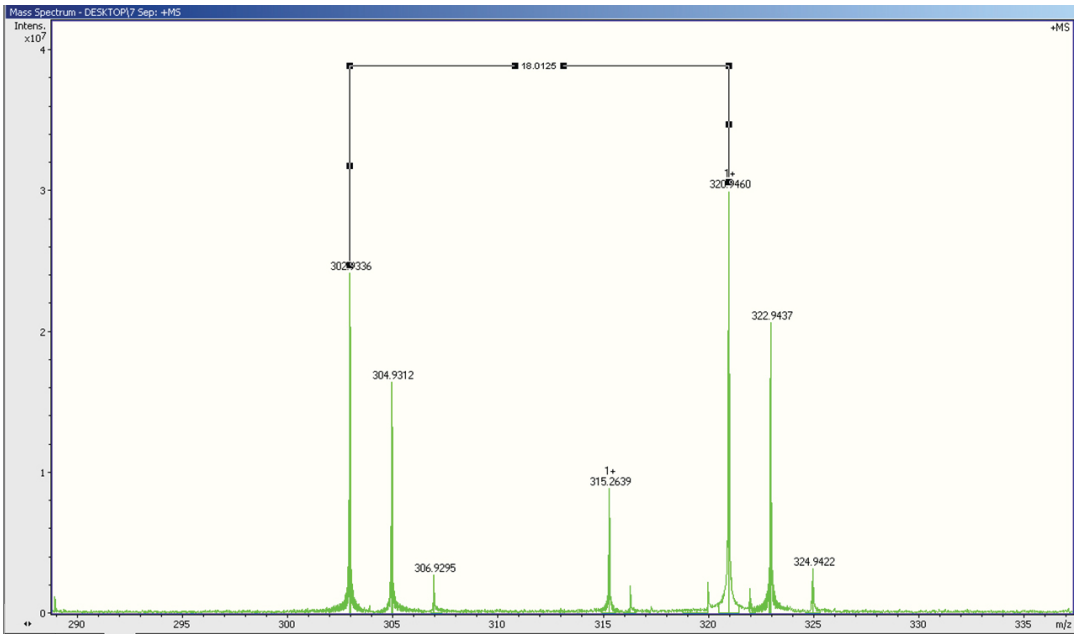


Fig. 4: Annotated difference between the m/z ratios of $AuCl_2(H_2O)_2^+$ and $AuCl_2(H_2O)_3^+$

4. Results

The identified complex species have been listed in Table 1. Species with differing hydration states were grouped together to better organize complexes. Monoisotopic mass to charge ratios have also been listed as this value is the most easily accessed when processing at the experimental data. Determining which peak to use is sometimes unclear so that both the lowest *m/z* peak and the highest abundance peak in the data have been recorded.

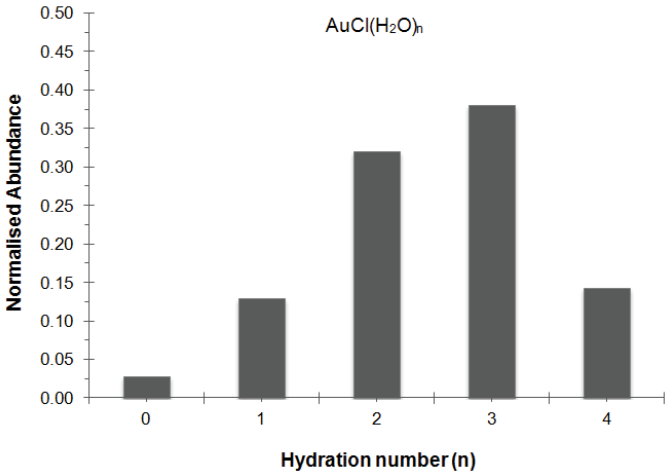
Monoisotopic *m/z* refers to the peak in mass spectrometry data that has the lowest corresponding mass to charge ratio, or the leftmost peak graphically. Chemical formula refers to the formula entered into the simulation program. To better group species together, species with increasing hydration states are ordered consecutively. For consistency, the hydration state is included even when there is no water present in the compound. Abundance of the lowest *m/z* peak corresponds to the monoisotopic *m/z* value in counts (cnt). The abundance of the highest peak in simulation was also recorded for reference as not all species had the highest peak at the lowest *m/z* ratio.

The abundance intensities have then been plotted for each group of complexes. The hydration state has been placed on the *x*-axis while the abundance intensity of the first peak is on the *y*-axis.

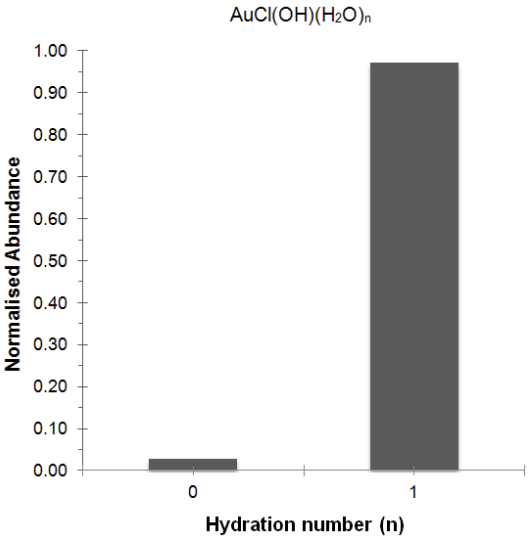
The uncertainty for normalised abundance can be derived from the uncertainty in the abundance data. However the number of counts (cnt) is six or seven orders of magnitude larger than the smallest unit of measurement. Thus while the normalised abundance varies slightly, the range of uncertainty is not visible on the graphs shown.

Monoisotopic *m/z*	Chemical formula	Abundance of lowest *m/z* peak in simulation (cnt)	Abundance of highest peak in simulation
266.90	$AuCl_2(H_2O)_0$	2.07 E+06	2.07 E+06
284.91	$AuCl_2(H_2O)_1$	9.71 E+06	9.71 E+06
302.92	$AuCl_2(H_2O)_2$	2.42 E+07	2.42 E+07
320.94	$AuCl_2(H_2O)_3$	2.87 E+07	2.87 E+07
338.95	$AuCl_2(H_2O)_4$	1.07 E+07	1.07 E+07
248.94	$AuCl(OH)(H_2O)_0$	6.13 E+05	6.13 E+05
266.95	$AuCl(OH)(H_2O)_1$	2.07 E+07	2.07 E+07
338.86	$AuCl_2(HCl)_2(H_2O)_0$	1.07 E+07	7.12 E+06
356.87	$AuCl_2(HCl)_2(H_2O)_1$	3.76 E+06	4.88 E+06
374.88	$AuCl_2(HCl)_2(H_2O)_2$	2.52 E+07	3.32 E+07
392.89	$AuCl_2(HCl)_2(H_2O)_3$	2.19 E+07	2.64 E+07
410.90	$AuCl_2(HCl)_2(H_2O)_4$	1.59 E+06	1.49 E+06
568.79	$Au_2Cl_5(H_2O)_0$	4.75 E+06	6.50 E+06
586.79	$Au_2Cl_5(H_2O)_1$	4.11 E+06	6.07 E+06
604.80	$Au_2Cl_5(H_2O)_2$	1.29 E+06	2.24 E+06
550.81	$Au_2Cl_4(OH)(H_2O)_0$	8.34 E+05	6.70 E+05
568.82	$Au_2Cl_4(OH)(H_2O)_1$	4.75 E+06	6.50 E+06
586.83	$Au_2Cl_4(OH)(H_2O)_2$	4.11 E+06	6.07 E+06
604.84	$Au_2Cl_4(OH)(H_2O)_3$	1.29 E+06	2.24 E+06

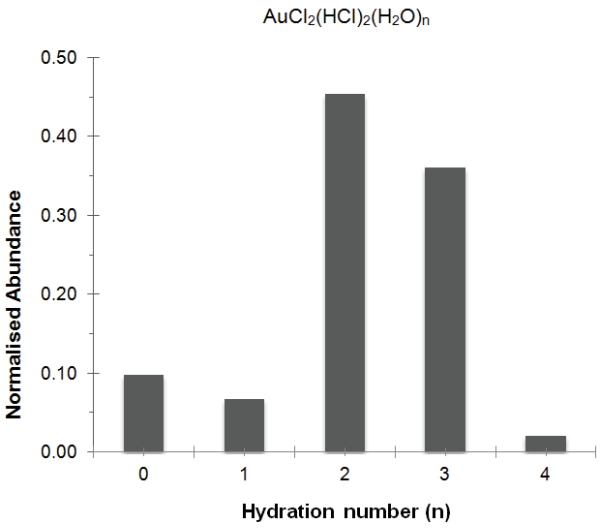
Table 1: List of identified species



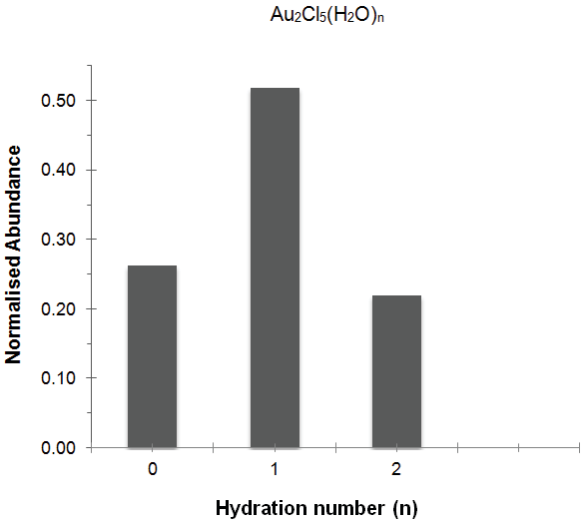
Graph 1: Normalised abundance intensity of $AuCl(H_2O)_n$



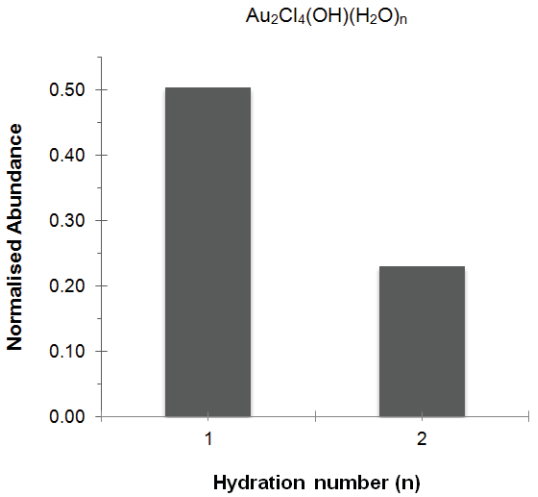
Graph 2: Normalised abundance intensity of $AuCl(OH)(H_2O)_n$



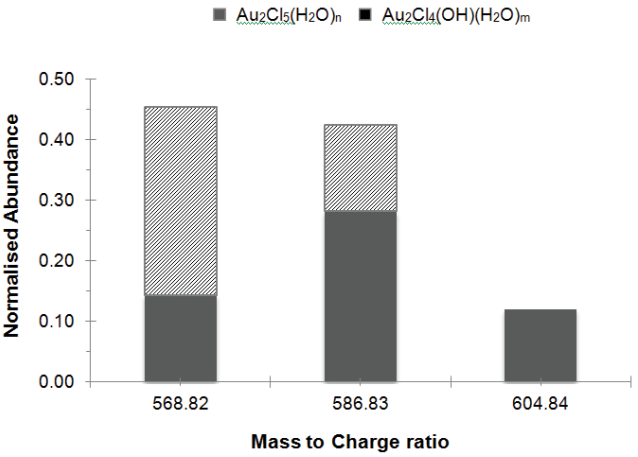
Graph 3: Abundance intensity of $AuCl_2(HCl)_2(H_2O)_n$



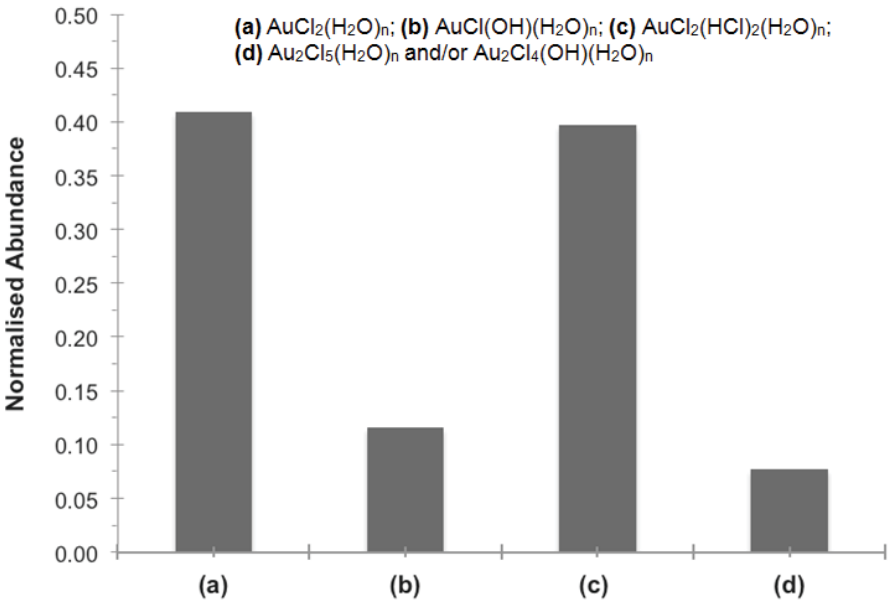
Graph 4: Abundance intensity of $Au_2Cl_5(H_2O)_n$



Graph 5: Abundance intensity of $Au_2Cl_4(OH)(H_2O)_n$



Graph 6: Normalised abundance of $Au_2Cl_5(H_2O)_n$ (n=0,1,2) and $Au_2Cl_4(OH)(H_2O)_m$ (m=1,2,3)



Graph 7: Abundance intensity of all groups of identified species

5. Interpretation of Results

5.1 Key cluster types

Five main cluster types have been identified, they are: $AuCl_2(H_2O)_n$ (n=0-4), $AuCl(OH)(H_2O)_n$ (n=0-1), $AuCl_2(HCl)_2(H_2O)_n$ (n=0-4), $Au_2Cl_5(H_2O)_n$ (n=0-2), $Au_2Cl_4(OH)(H_2O)_n$ (n=0-3). The most prevalent groups are $AuCl_2(H_2O)_n$ and $AuCl_2(HCl)_2(H_2O)_n$, accounting for nearly 80% of the identified peaks.

5.2 Hydration

From the results it can be seen that, at room temperature, solvation is present and significant in the chemistry of cluster formation. In particular, poly-solvated ions with hydration states of 1, 2 and 3 are the most stable. The distributions of hydration states can be demonstrated qualitatively. For example, the hydration of $AuCl_2$ can be expressed in the following chemical equilibrium:

$$AuCl_2 + n\,H_2O \rightleftharpoons AuCl(H_2O)_n$$

The equilibrium constant K_c for this reaction can thus be expressed as:

$$K_c = [AuCl(H_2O)_n]/([AuCl_2][H_2O]^n)$$

Rearranging this equation to give the concentration of the hydrated product:

$$[AuCl(H_2O)_n] = K_c\,[AuCl_2][H_2O]^n$$

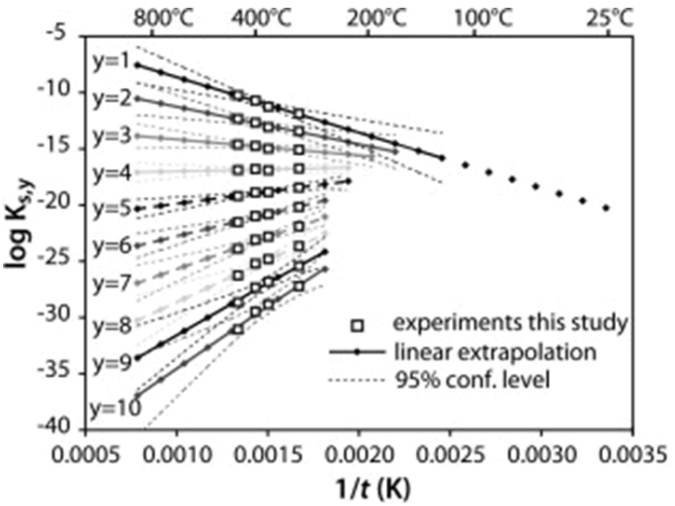
As $[AuCl_2]$ remains constant when comparing the cases for different hydration states, $[AuCl(H_2O)_n]$ is therefore only dependent on K_c and $[H_2O]^n$. As *n* increases, the value of $[H_2O]^n$ would therefore increase drastically. However, the concentrations seen experimentally do not show this trend for all values of *n*. Instead, the relative abundance of increasingly hydrated species (as designated by the hydration number, *n*) first increases and then decreases. This suggests that the equilibrium constant decreases as *n* increases. It is also known that the equilibrium constant is a function of temperature and pressure. As such further research would be needed on the details of how these variables interact.

5.3 Thermodynamic Stability

One way of looking at the effect of changes in temperature and pressure on the formation of multiply solvated complexes is through the use of Van 't Hoff's equation.

$$\ln(K_c) = (\Delta S^{\ominus})/R - (\Delta H^{\ominus})/RT$$

A graph of $\ln(K_c)$ against 1/T can thus be plotted using experimental equilibrium constants and temperatures. This is known as a *Van 't Hoff plot.* This process has been done for AuCl and its hydration states by Hurtig and William-Jones.



Graph 8: Linearly Extrapolated Values of Log K versus Reciprocal Temperature (1/t) for $AuCl(H_2O)_y$ (y = 1-10) (from Hurtig and William-Jones)

As the slope of a *Van 't Hoff plot* is $(-\Delta H^{\ominus}/R)$, the enthalpy change can be seen to be dependent on the hydration number. When hydration numbers are low (1-3), the slope is negative, thus enthalpy change is positive and the reaction is endothermic. When the hydration numbers become larger (5-10), the slope becomes positive and the reactions become exothermic.

The gradients and intercepts of these equations can then be used to predict the thermodynamic properties of each reaction, i.e. changes in enthalpy (ΔH) and entropy (Δ*S*). After ΔH and ΔS have been determined, the spontaneity of each reaction can be predicted by calculating Gibb's free energy (ΔG):

$$\Delta G = \Delta H - T\Delta S$$

6. Evaluation

6.1 Experimental Error

6.1a Random Error

The largest source of random error is due to contamination by previous experiments on the same equipment. Zinc chloride and zinc sulfate had previously been analysed and their peaks have therefore been identified and disregarded as irrelevant to the study. However, some peaks were also not identified. This could have affected the results, as it would mean a gold complex may not have been recorded. Given additional time, a simple program could have been written to simulate all possible combinations of elements present in the sample to identify the less significant peaks.

Given additional time, multiple trials of mass spectrometry would be performed to create multiple mass spectra, reducing the random error on the relative abundances of each species as well as giving data, from several trials, on the degree of variation.

6.1b Systematic Error

The systematic error in this study is minimal in this experiment due to the precision of the equipment used. The solution of gold chloride has systematic error due to impurity in the source chemical, uncertainty of the analytical balance and the volumetric flask. The percentage uncertainty for molarity is 0.01%. This error may affect the relative distributions of complexes, however the uncertainty is very low has minimal effect on the trends found.

Another source of error is when approximations are made when identifying species from the mass spectrograph. When identifying the peaks in the data set, sometimes the mass to charge ratios in simulations are not identical to those in the experimental data. Matches were considered to be those with differences in mass to charge ratio of less than 0.1. This error could lead to incorrect identification of species but is not significant otherwise.

6.2 Evaluation of Sources

The sources used were of high reliability because they were all either peer-reviewed academic articles, or open resources published by universities and industrial material providers. However there is a lack of previous studies to compare my results to, limiting the validity of my findings.

The primary data set was also limited in several ways. Firstly, there was no range in temperature and pressure as the data was only collected at room temperature and low pressures. This limits the relevance of the conclusions drawn to a small set of conditions. This data set is also unable to illustrate how the relative distributions of cluster types and hydration states change as conditions change. Secondly, since the conditions chosen are similar to those very near the Earth's surface, this would mean that in a real scenario, gold-carrying liquids may have already have deposited a significant portion of their gold content before reaching the conditions tested in this study.

6.3 What could be done next?

The next step in understanding the process of gold deposit formation by mass spectrometry is to study a range of conditions. This would provide insight into how distributions of clusters and hydration states change as the conditions continually change.

Furthermore, experimental studies of gold solubility at hydrothermal temperatures have shown that pH and redox states are the primary determinants of solubility (Barnes and Rose 2064). These two variables will therefore be a focus of further research after the complexation of gold (III) chloride in aqueous solution at room temperature is better understood.

7. Acknowledgements

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