



HAL
open science

Geometric Graphs to Study Ceramic Decoration

Thomas Huet

► **To cite this version:**

Thomas Huet. Geometric Graphs to Study Ceramic Decoration. Mieko Matsumoto; Espen Uleberg. Oceans of Data. Proceedings of the 44th Conference on Computer Applications and Quantitative Methods in Archaeology, Archaeopress, pp.311-323, 2018, 9781784917302. hal-02913656

HAL Id: hal-02913656

<https://hal.science/hal-02913656>

Submitted on 10 Aug 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Oceans of Data

Proceedings of the 44th Conference on
Computer Applications and
Quantitative Methods in Archaeology

Edited by

Mieko Matsumoto and Espen Uleberg





ARCHAEOPRESS PUBLISHING LTD
Summertown Pavilion
18-24 Middle Way
Summertown
Oxford OX2 7LG

www.archaeopress.com

ISBN 978 1 78491 730 2
ISBN 978 1 78491 731 9 (e-Pdf)

© Archaeopress and the authors 2018

Language Editing: Rebecca Cannell
Cover Design: Bjarte Einar Aarseth

All rights reserved. No part of this book may be reproduced, or transmitted, in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior written permission of the copyright owners.

Printed in England by Oxuniprint, Oxford

This book is available direct from Archaeopress or from our website www.archaeopress.com

Contents

Foreword.....	v
INTRODUCTION	1
Oceans of Data: Creating a Safe Haven for Information	3
Christian-Emil ORE	
Theorising the Digital: A Call to Action for the Archaeological Community	11
Sara PERRY and James Stuart TAYLOR	
ONTOLOGIES AND STANDARDS	23
Is that a Good Concept?	25
George BRUSEKER, Maria DASKALAKI, Martin DOERR, and Stephen STEAD	
Sculptures in the Semantic Web Using Semantic Technologies for the Deep Integration of Research Items in ARIADNE	33
Philipp GERTH, Dennis Mario BECK, Wolfgang SCHMIDLE, and Sebastian CUY	
Formalization and Reuse of Methodological Knowledge on Archaeology across European Organizations ...	45
Cesar GONZALEZ-PEREZ, Patricia MARTÍN-RODILLA, and Elena Viorica EPURE	
Linked Open Data for Numismatic Library, Archive and Museum Integration	55
Ethan GRUBER	
Sustainability = Separation: Keeping Database Structure, Domain Structure and Interface Separate	63
Ian JOHNSON	
Systematic Literature Review on Automated Monument Detection: A Remote Investigation on Patterns within the Field of Automated Monument Detection	69
Karl Hjalte Maack RAUN and Duncan PATERSON	
Bioarchaeology Module Loading...Please Hold. Recording Human Bioarchaeological Data from Portuguese Archaeological Field Reports	85
Ana Lema SEABRA, Filipa Mascarenhas NETO, and Cristina BARROSO-CRUZ	
Methodological Tips for Mappings to CIDOC CRM	89
Maria THEODORIDOU, George BRUSEKER, and Martin DOERR	
An Ontology for a Numismatic Island with Bridges to Others	103
Karsten TOLLE, David WIGG-WOLF, and Ethan GRUBER	
Integrating Analytical with Digital Data in Archaeology: Towards a Multidisciplinary Ontological Solution. The Salamis Terracotta Statues Case-Study	109
Valentina VASSALLO, Giusi SORRENTINO, Svetlana GASANOVA, and Sorin HERMON	
FIELD AND LABORATORY DATA RECORDING AND ANALYSIS	119
Integrated Methodologies for Knowledge and Valorisation of the Roman <i>Casinum</i> City	121
Michela CIGOLA, Arturo GALLOZZI, Leonardo PARIS, and Emanuela CHIAVONI	
A Multidisciplinary Project for the Study of Historical Landscapes: New Archaeological and Physicochemical Data from the ‘Colline Metallifere’ District	135
Luisa DALLAI, Alessandro DONATI, and Vanessa VOLPI	
From Survey, to 3D Modelling, to 3D Printing: Bramante’s Nymphaeum Colonna at Genazzano	147
Tommaso EMLER and Adriana CALDARONE	
Towards a National Infrastructure for Semi-Automatic Mapping of Cultural Heritage in Norway	159
Martin KERMIT, Jarle Hamar REKSTEN, and Øivind Due TRIER	

Experiments in the Automatic Detection of Archaeological Features in Remotely Sensed Data from Great Plains Villages, USA	173
Kenneth L. KVAMME	
Interpolating 3D Stratigraphy from Indirect Information	185
Lutz SCHUBERT, Ana PREDOI, and Keith JEFFERY	
Closing a Gap with a Simple Toy: How the Use of the Tablet Affected the Documentation Workflow during the Excavations of the Rozprza Ring-Fort (Central Poland)	197
Jerzy SIKORA and Piotr KITTEL	
Supercomputing at the Trench Edge: Expediting Image Based 3D Recoding	207
David STOTT, Matteo PILATI, Carsten MEINERTZ RISAGER, and Jens-Bjørn Riis ANDRESEN	
Semi-Automatic Mapping of Charcoal Kilns from Airborne Laser Scanning Data Using Deep Learning	219
Øivind Due TRIER, Arnt-Børre SALBERG, and Lars Holger PILØ	
Documenting Facades of Etruscan Rock-Cut Tombs: from 3D Recording to Archaeological Analysis	233
Tatiana VOTROUBEKOVÁ	
ARCHAEOLOGICAL INFORMATION SYSTEMS	243
Fasti Online: Excavation, Conservation and Surveys. Twelve Years of Open Access Archaeological Data Online	245
Michael JOHNSON, Florence LAINO, Stuart EVE, and Elizabeth FENTRESS	
DOHA — Doha Online Historical Atlas	253
Michal MICHALSKI, Robert CARTER, Daniel EDDISFORD, Richard FLETCHER, and Colleen MORGAN	
Digital Archives — More Than Just a Skeuomorph	261
Emily NIMMO and Peter MCKEAGUE	
When Data Meets the Enterprise: How Flanders Heritage Agency Turned a Merger of Organisations into a Confluence of Information	273
Koen VAN DAELE, Maarten VERMEYEN, Sophie MORTIER, and Leen MEGANCK	
GIS AND SPATIAL ANALYSIS	285
Crossroads: LCP — Model Testing and Historical Paths During the Iron Age in the North-East Iberian Peninsula (4th to 1st Centuries BC)	287
Joan Canela GRÀCIA and Núria Otero HERRAIZ	
Boundaries of Agrarian Production in the Bergisches Land in 1715 AD	299
Irmela HERZOG	
Geometric Graphs to Study Ceramic Decoration	311
Thomas HUET	
Vertical Aspects of Stone Age Distribution in South-East Norway	325
Mieko MATSUMOTO and Espen ULEBERG	
3D AND VISUALISATION	337
Emerging Technologies for Archaeological Heritage: Knowledge, Digital Documentation, and Communication	339
Martina ATTENNI, Carlo BIANCHINI, and Alfonso IPPOLITO	
New Actualities for Mediterranean Ancient Theaters: the ATHENA Project Lesson	353
Carlo BIANCHINI, Carlo INGLESE, and Alfonso IPPOLITO	
Archaeology and Augmented Reality. Visualizing Stone Age Sea Level on Location	367
Birgitte BJØRKLI, Šarūnas LEDAS, Gunnar LIESTØL, Tomas STENARSON, and Espen ULEBERG	
A Virtual Reconstruction of the Sun Temple of Niuserra: from Scans to ABIM	377
Angela BOSCO, Andrea D'ANDREA, Massimiliano NUZZOLO, Rosanna PIRELLI, and Patrizia ZANFAGNA	

A 3D Digital Approach for the Study and Presentation of the Bisarcio Site	389
Paola DERUDAS, Maria Carla SGARELLA, and Marco CALLIERI	
The Role of Representation in Archaeological Architecture	399
Mario DOCCI, Carlo INGLESE, and Alfonso IPPOLITO	
Digital Archaeological Dissemination: Eleniana Domus in Rome	409
Tommaso EMLER	
On Roof Construction and Wall Strength: Non-Linear Structural Integrity Analysis of the Early Bronze Age Helike Corridor House	421
Mariza Christina KORMANN, Stella KATSAROU, Dora KATSONOPOULOU, and Gary LOCK	
An Exploratory Use of 3D for Investigating a Prehistoric Stratigraphic Sequence	433
Giacomo LANDESCI, Jan APEL, Stefan LINDGREN, and Nicolò DELL'UNTO	
Les gestes retrouvés: a 3D Visualization Approach to the Functional Study of Early Upper Palaeolithic Ground Stones	447
Laura LONGO, Natalia SKAKUN, Giusi SORRENTINO, Valentina VASSALLO, Dante ABATE, Vera TEREHINA, Andrei SINITSYN, Gennady KHLOPACHEV, and Sorin HERMON	
Enhancing Archaeological Interpretation with Volume Calculations. An Integrated Method of 3D Recording and Modeling	457
Giulio POGGI and Mirko BUONO	
3D Spatial Analysis: the Road Ahead	471
Martijn VAN LEUSEN and Gary NOBLES	
COMPLEX SYSTEMS SIMULATION	479
Weaving the Common Threads of Simulation and Formation Studies in Archaeology	481
Benjamin DAVIES	
Evolving Hominins in HomininSpace: Genetic Algorithms and the Search for the ‘Perfect’ Neanderthal	495
Fulco SCHERJON	
An Agent-Based Approach to Weighted Decision Making in the Spatially and Temporally Variable South African Paleoscape	507
Colin D. WREN, Chloe ATWATER, Kim HILL, Marco A. JANSSEN, Jan C. DE VYNCK, and Curtis W. MAREAN	
TEACHING ARCHAEOLOGY IN THE DIGITAL AGE	523
Archaeological Education for a Digital World: Case Studies from the Contemporary and Historical US	525
Anna S. AGBE-DAVIES	
Teaching Archaeology or Teaching Digital Archaeology: Do We Have to Choose?	533
Sylvain BADEY and Anne MOREAU	
DOMUS: Cyber-Archaeology and Education	541
Alex DA SILVA MARTIRE and Tatiana BINA	
Digital Data Recording at Circus Maximus: A Recent Experience	547
Alessandro VECCHIONE and Domenica DININNO	
Teaching GIS in Archaeology: What Students Focus On	555
Mar ZAMORA MERCHÁN and Javier BAENA PREYSLER	

Geometric Graphs to Study Ceramic Decoration

Thomas HUET

UMR5140, Archéologie des Sociétés Méditerranéennes, CNRS, Université Paul-Valéry 3, Montpellier
thomashuet7@gmail.com

Abstract

As with geography, ceramic decorations are essentially spatial organisations of features. Therefore, they should be analysed with spatial indexes. But spatial analyses, at the shard or the complete ceramic scale, are often difficult to set up, mostly because of the contiguity of graphical features.

This paper presents a new method to record and analyse ceramic decoration. We use graph theory, with a GIS interface and Python programming, to analyse ceramic decoration in a bottom-up process. A priori definitions are minimal and only concern elementary units (morphological, graphical and plastic) which compose the ceramic.

The studied corpus is composed of ceramic decorations belonging to the Mailhac I facies (Late Bronze Age), characterised by complex figurative compositions. Each decoration – complete or fragmented – is considered as a spatialized network (i.e. geometric graph). Graph theory provides tools to record and measure proximities between units and normalised indexes to compare different decorations, whatever their completeness. The GIS offers a graphic interface and ensures the correctness of spatial relationships between these units. The typology of these units is realised in a hierarchical oriented graph. This structure allows processes of generalisation (going up the tree) and specification (going down the tree), permitting comparison between units with different kinds of resolution and/or complexity. The method presented here can be used for other types of mediums (statuary, rock art, etc.).

Keywords: ceramics, decorations, network analysis, graph theory, GIS, python

Introduction

Theoretical background

Due to their abundance in archaeological layers (often as shards) and their short life span (Demoule, 2009), ceramics have, since the beginning of archaeology, represented one of the most detailed typological series of Later Prehistory (Neolithic to Iron Age) and more broadly of pre-industrial societies. While generic forms of ceramics (defined by the maximal aperture, height, width and width of the wall) depend on their functions (store, cook, consume) and show typological convergence through time and space, a large degree of freedom is allowed in the addition of plastic elements (pedestal base, carination, rolled rim, etc.) and decorations (vertical grooves, roll-wheel impressions, colours, etc.). The isochrestic variation (Sackett, 1990) assumes that the more complex an artefact is, the less likely it is that two different cultures use the same combination to reach the same result. The respective choices, within a tradition, are synonymous of the notion of 'style'. These 'styles' have a classificatory value (etic value) and a potential emic value that participate to the identification of cultural facies (Le Quellec, 1998), even if the granularity of these facies is variable (Dietler and Herbich, 1994). Ceramic decorations, because they are largely disconnected from technical constraints, are data of prime importance in recognising different 'styles'.

Despite their omnipresence in archaeology, decorations are still relatively unexploited; multivariate analyses are often the culmination of the statistical process and spatial analyses of graphical patterns is commonly scarce (see for example Desenne, 2003). At the graphical units level (the thinnest elements of the decoration), typologies are usually developed with families (or types) divided into varieties (or subtypes). But, the gathering of graphical units into one – rather than another – family is often empirical, especially for schematic shapes. Furthermore, the proximities *between* these families (inter-variability) and *within* these families (intra-variability) are generally not calculated (Figures 1 and 2).

Van Berg (1994) proposed a methodology, inspired by linguistics, to study decoration of Linear Pottery

composition level	description
patterns	organisation of graphical units
figures	organisation of patterns
decorative scheme	organisation of figures

Table 1. Schema of Van Berg's grid of analysis for the different levels of composition of graphical units in the decoration (after Van Berg, 1994). The decorative scheme is the decoration.

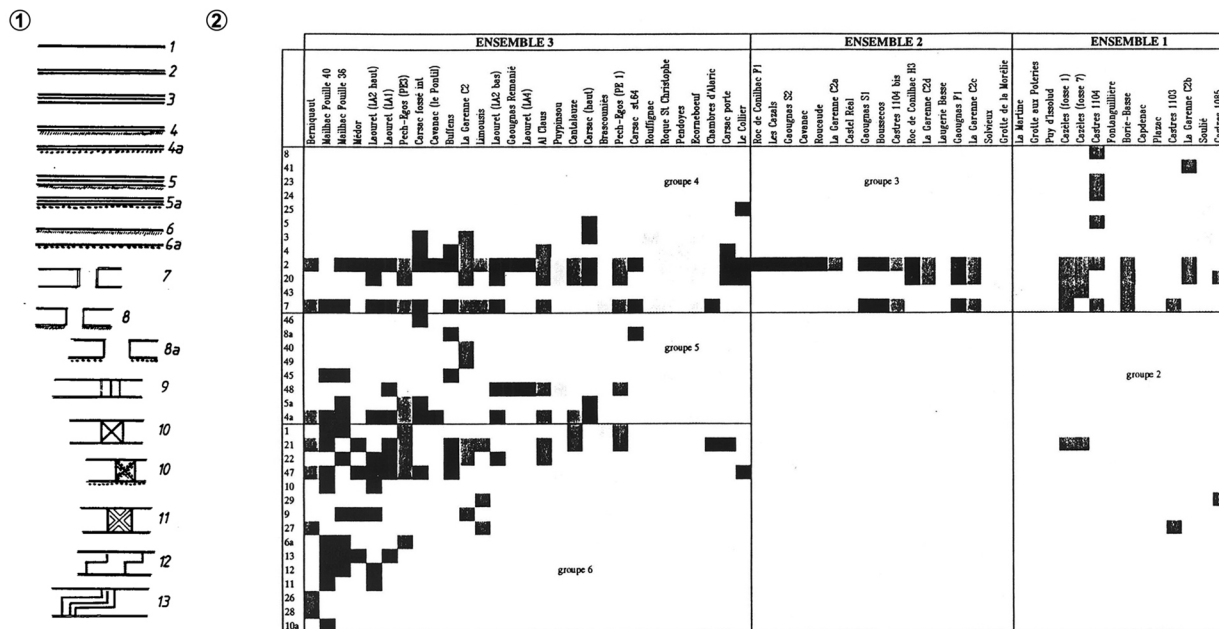


Figure 1. Seriation of ceramic decorations in the South of France during the Late Bronze Age (after Carozza, 1997, detail). (1) Most basic elements considered, graphical units ('stairs', 'lines', 'crosses', etc.), are already a grouping of geometrical shapes. Inter-variabilities between these groups of decorations are not evaluated. (2) Seriated data frame based on presence/absence of these groups of decorations.

Clés	1	2	3	4	5	6
XIV						
XV a						
XV b						
XVI						
XVII						
XVIII a						
XVIII b						
XVIII c						

Figure 2. Typological data frame of the decoration units (after Gómez de Soto, 2003). Each row represents a type (xiv: stick signs with bifid extremities, xv: anthropomorphic, xvi: barbed signs, xvii: pectiniform signs, xviii: zoomorphic). Each column represents a regional variation of this type (1: Rhone region, 2: Bourget lake, 3: Western centre, 4: Languedoc and Catalonia, 5: Massif Central, 6: East of France). In each of the frame's cells (for ex., cell xiv, 4), variability of the type is illustrated by examples. Intra-variabilities within a cell, and inter-variabilities between cells of the same row, are not calculated.

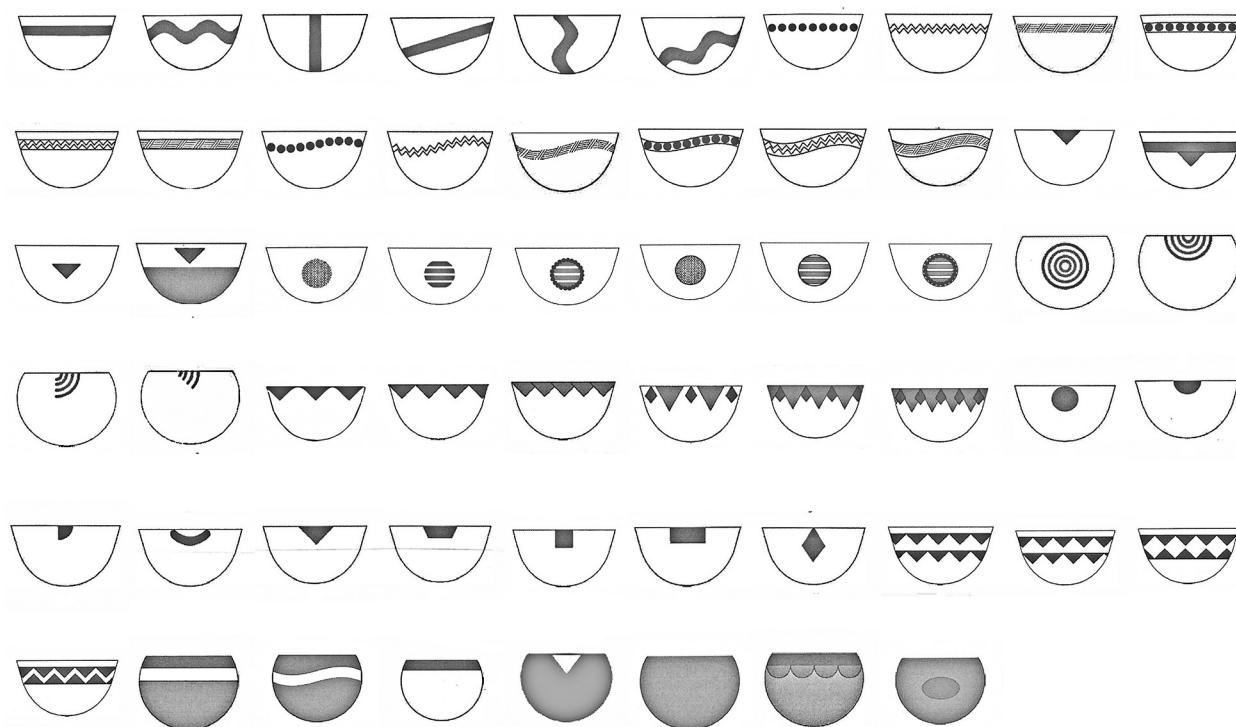


Figure 3. Compilation of Gallin's typology of Kobadi's ceramic compositions (after Gallin, 2011). Definition of a priori classes leads to a considerable amount of descriptions at all levels, for motifs (patch pattern, line pattern, weave pattern, etc.), figures (banner, ribbon, pendant, inset, coverage, etc.) and location (near the rim, on the neck, on the upper part of the belly, etc.). A consequence is the massive use of infographic to schematise all cases; the archaeologists cut themselves off from the source drawings during the analysis process. Once again, definitions of the decoration's location on the ceramic surface remain also largely qualitative; relations between different spatial configurations are not calculated.

ceramics (LBK culture). However, application of this methodology to these ceramics only led to qualitative results. Van Berg considers two levels of analysis: the study of graphical units and the study of organisations of these graphical units. The first are likened to a vocabulary, the second to syntax or grammar (Table 1).

In France, Van Berg's 'systemic' methodology has inspired various scholars, who developed quantitative approaches to study ceramic decorations (among others Gallin, 2011; Manen, 2000). But in these studies, the schematism of graphical units, the difficulty of characterising them, the variability of decorations and the fragmentation of ceramics have represented real obstacles. For most detailed analyses, application of this methodology, or a similar methodology, has led to tedious descriptions and overly numerous categories, with high probabilities that most of them will be represented by a unique element (Figure 3).

As said previously, definition of different levels of organisation for graphical units was inspired by structural linguistics. At first, this distinction was useful to study rock art, like Palaeolithic cave paintings (Leroi-Gourhan, 1992) but, despite its theoretical interest, this approach is, in practice, not adequate. Language and

writing (subjects of linguistics), are linear sequences of semantic units. This linear sequence is known as the 'syntagmatic axis' where units follow each other (in column, in line, in boustrophedon, etc.) while the 'paradigmatic axis' refers to the signifiers of each of these units. Graphical units have spatial relationships that spread in different directions, and not only linearly. Whereas spatial analyses can be difficult to implement, due to the need for measurements (distances, directions, etc.), graph theory offers a heuristic tool to study ceramic decorations.

Research questions

We principally applied the tool to the decorated ceramics of Mailhac I, a Late Bronze Age facies (Bronze final IIIb, ca 900–750 BC) concentrated in the South of France (Languedoc) and North-eastern Spain (Catalonia). This ceramic facies is characterised by rectilinear geometrical and figurative decorations realised with a double tip instrument. Similar decorations, made with a single tip, occur also in France (Western centre and East). The semantic complexity of some of these decorations has led to hypotheses linked to a probable narrative function of the decoration: a mnemonic means to preserve myth structures (Zipf, 2006) or social

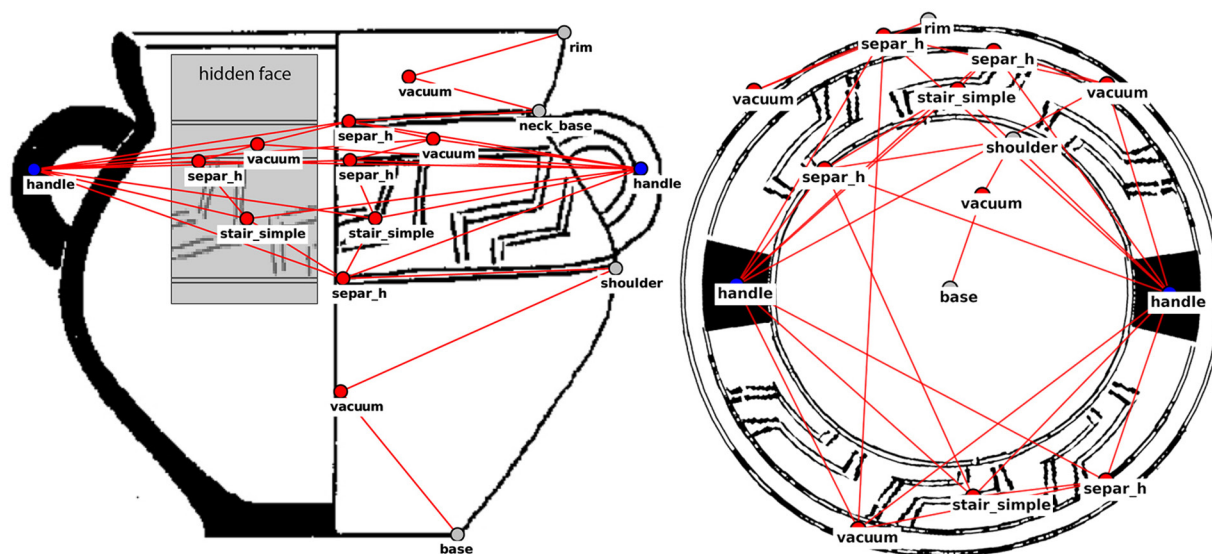


Figure 4. Equivalent graphs for the decorated ceramic from tomb 17 of Le Moulin necropolis, Late Bronze Age (Aude, France). Original document where only a quarter of the ceramic surface is presented (left, side view) and supposed topview from the same document. The 'stair' is assumed to be present six times on the whole ceramic (right, top view). Red nodes: graphical units; grey nodes: morphological units; blue nodes: plastic units.

schemes (Gómez de Soto, 2003). Comparisons with hieroglyphic and alphabetic writings have also been made (Nicolas and Combier, 2009).

Figuration (anthropomorphic, zoomorphic, etc.) appears in those regions, while ceramics of the rest of the European Bronze Age and the Early Iron Age are largely aniconic. The reasons for this reappearance are still poorly understood (Carozza, 1997). According to some scholars, the Mediterranean domain could be the inspiration for these figurations (Guilaine and Py, 2000), while others look towards the cultures of the North-Alpine Rhineland-Palatinat, Switzerland and eastern France (RSFO) (Gómez de Soto, 1993) and some consider them as a local innovation (Zipf, 2006). The arguments – based on the existence of identical graphical units, forms of ceramics, etc. – for each of these hypotheses are equally valid, and so the cause of this reappearance remains unresolved. Furthermore, it is quite probable that no help will come from the cross-dating of the elements of material culture (the chronological limits of 'cultures', 'facies', 'periods', etc. are too imprecise to detail this brief event), nor from the refinement of radiocarbon dating (the period partly belongs to the 'Hallstatt plateau'). Therefore, to progress in the understanding of the reappearance of figuration, we privilege an analysis of the semantic information firstly based on the signifiers. The purpose of our research is to go deeper in the identification of styles and typo-chronology by understanding filiations (predecessors, parentage, etc.) of ceramic decorations.

Data and case study

The development of the methodology has been done principally on the ceramic decorations coming from the necropolis of Le Moulin (Aude, France) in West Languedoc. Excavated during the fifties, the ceramics of the necropolis are actually inaccessible. We were able to work only from drawings and descriptions, which were not always precise, particularly concerning the presence and situation of coloured pigments (red, white) in the decoration. In the monograph of the necropolis (Janin *et al.*, 1998), drawings of ceramic decoration were not explicit concerning the total number of units present on the ceramic. We assume the information on which this reproduction is done by the archaeologist is sufficient although, in some cases, information has had to be extrapolated from drawings (Figure 4).

Geometric graph, a heuristic for ceramic decoration analyses

Graph theory (i.e. network analysis) offers a vocabulary and a conceptual framework to deal with notions of networks, relationships and neighbourhoods. A system can be represented by nodes connected (or not) to each other with edges. Each decoration, complete ceramic or shard, is considered as a graph. Each node, called here a unit, has a type (for example, horse, vacuum, handle, etc.) belonging to the decoration (plastic and graphical units), or to the shape (morphological units) of the ceramic. Relationships between units are modelled

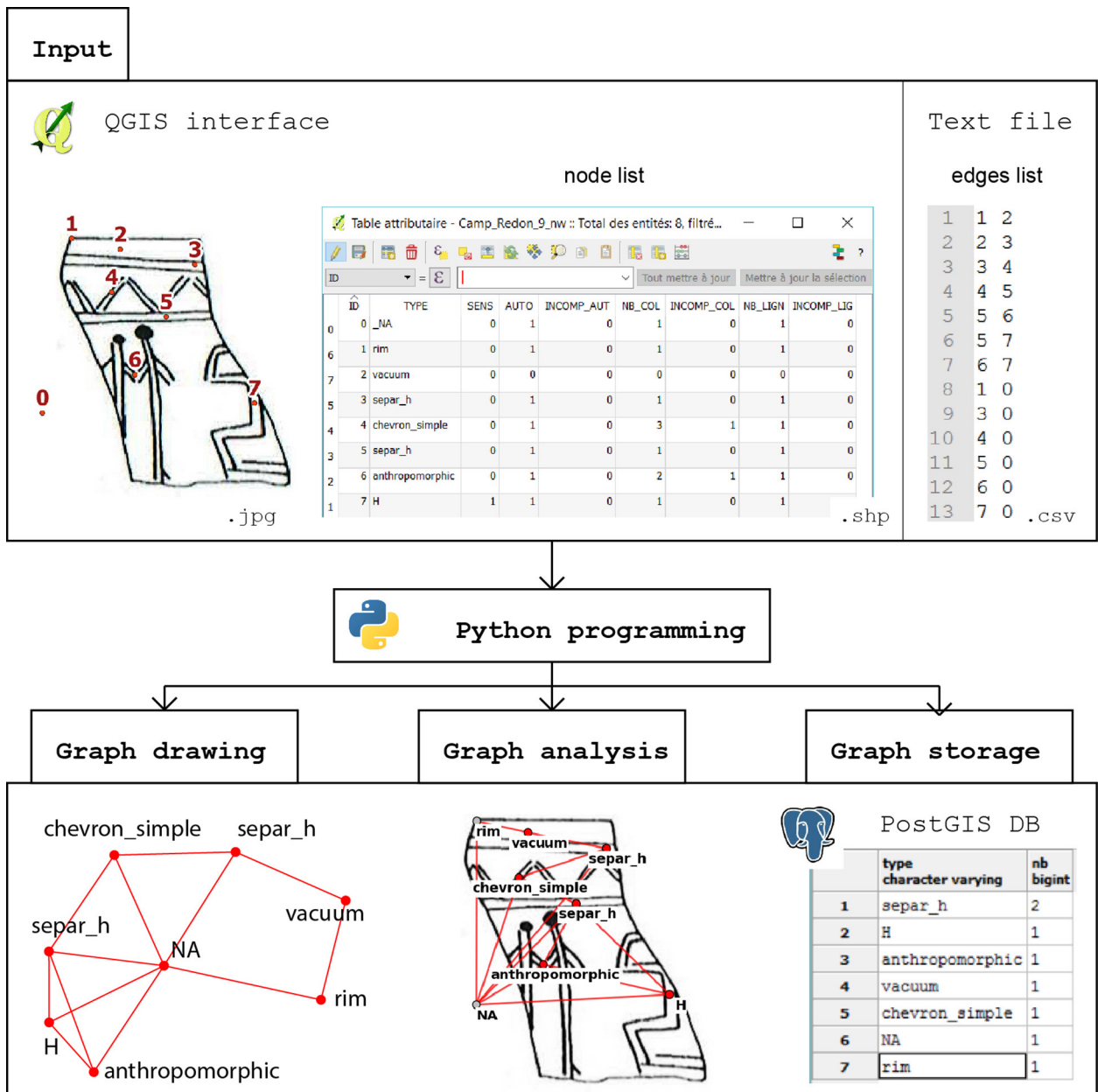


Figure 5. Schema of the workflow. The GIS interface (QGIS) permits us to maintain a permanent link with the original decoration. The Python libraries used to manage the layer of nodes (a shapefile) are mostly 'ogr', 'fiona' and 'shapely'. The text file, where edges are recorded, is managed with the 'csv' library. The drawing of the decoration, a raster file, is managed by the 'Image' library. The graph is created and analysed with the 'networkx' library. Connection with the PostGIS database, to store data, is handled by the 'psycopg2' library.

qualitatively: an edge exists between two nodes when they are close one to the other (see below). At first, there is no need to know precisely the centimetre distance and azimuth between two or more units. An important piece of information is the understanding of the neighbourhood of a given unit. Secondly, measurements between units can be calculated in the GIS (scaled and oriented).

According to Tobler's spatial fundamental law, 'everything is related to everything else but near things

are more related than distant things' (Tobler, 1970). In graph theory, Tobler's 'everything' is the graph itself with its global indexes (connectivity, distribution of connections, etc.), equivalent in geography to Second Order Neighbourhood Analysis, while the 'near things' are local indexes of nodes and edges (locations in the graph, neighbourhoods, etc.), and equivalent to First Order Neighbourhood Analysis.

Nodes are spatialized in the GIS as a shapefile (.shp) of points. In parallel, a list of connections between these

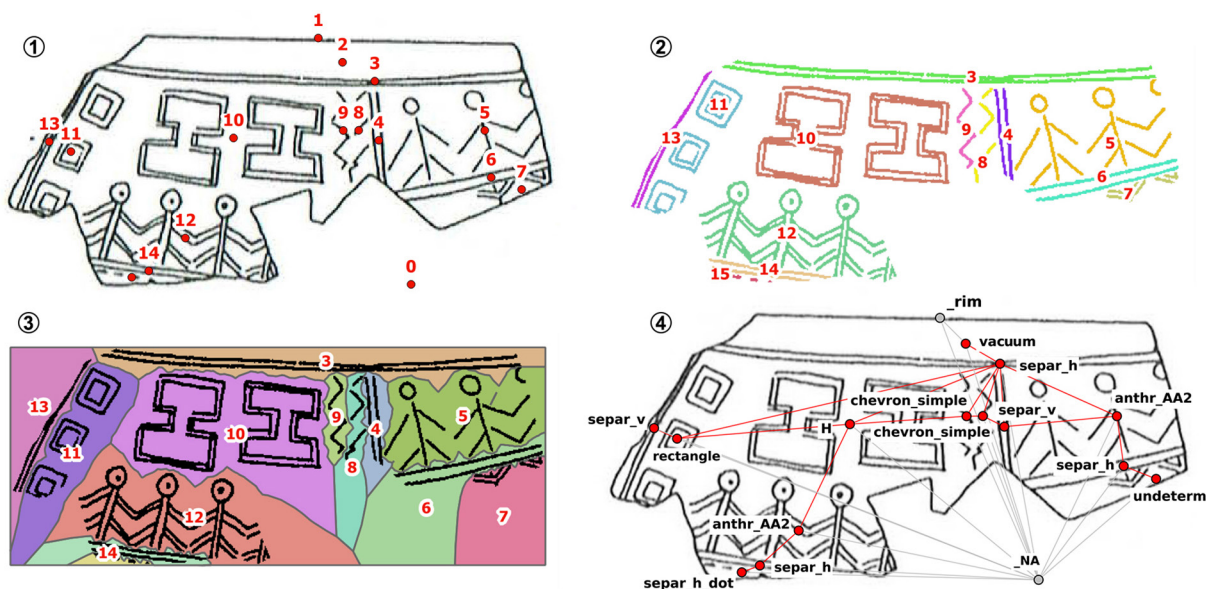


Figure 6. Complete process of composition recording for a decorated shard from Tonnerre I (Hérault, France), Late Bronze Age. 1: Opening of the drawing in QGIS and recording of the graphical units as a shapefile of points; 2. Vectorisation of the drawing (a raster) with Python's 'osgeo.gdal.Polygonize'; 3. Voronoi cells for the vectorised graphical units. Voronoi cells are synonymous with Thiessen polygons and equivalent to the mathematical morphological operator SKIZ by Influence Zone (SKIZ). Any location inside the Voronoi cell is closer to its graphical unit than any of the other sample points. The dual graph of a Voronoi diagram is a Delaunay triangulation for the same set of nodes; 4. Result of the geometric graph recording with labels showing the types of nodes; those which share a limit of their Voronoi cells will also share an edge in the geometrical graph (red nodes: graphical units, grey nodes: morphological units).

nodes is written in a text file (.csv). For each decoration a single shapefile for nodes and a single text file for edges are created. Programming offers the possibility to mix GIS, graph theory and database in a single interface. We used Python (v. 2.7), a multi-paradigm language, with its numerous libraries (Figure 5).

A characteristic of graph theory is that, unless otherwise specified, the only important thing is how nodes are connected. As a result, there is no rule for their representation (Mathis, 2003). This allows us to register drawings realised in different manners: front view, top view, unfolded view, etc.(see Figure 4). For the spatialized units, and the definition of their relationship, we assume that two or more units share an edge (i.e. are connected) when there is no other unit between them. In other words, a link exists when their Voronoi cells are contiguous. This can be represented as a partition of the whole space of the decoration (Figure 6).

Type of Units

Ceramics can be considered as a set of morphological features (type of rim, neck, shoulder, etc.), plastic features (like handles) and graphical features. Therefore, to record and analyse ceramic decorations, we distinguish three types of Units (U): Morphological Units (UM), Plastic Units (UP) and Graphical Units (UG).

These units (UM, UP, UG) are the most basic and only elements needed for the study of ceramic decoration. The decoration could therefore be considered as a 3-mode graph. Typology of the units is recorded in a single text file (.csv) where each line records a predecessor and one of its successors. This hierarchical structure is a particular case of a directed graph; it is a tree where units share an edge with only one predecessor. For example, these three lines: 'U;UM' and 'U;UP' and 'U;UG' are interpreted as: 'types UM, UP and UG are subtypes of U' or 'UM, UP and UG inherit from U' (Figure 7).

As said, each successor inherited from its predecessors. This allows a dynamical and recursive definition of each unit. For example, a 'horse' is defined as Figure 8.

This hierarchical structure permits comparison between ceramics with different kinds of resolution by a process of generalisation (by going up the tree) or specification (by going down the tree). The typology of units can easily be changed, by a simple editing of the text file, and employed for other bodies of material.

Morphological Units (UM)

We define the UM as continuous parts of the ceramic support. A given type of UM is only represented once

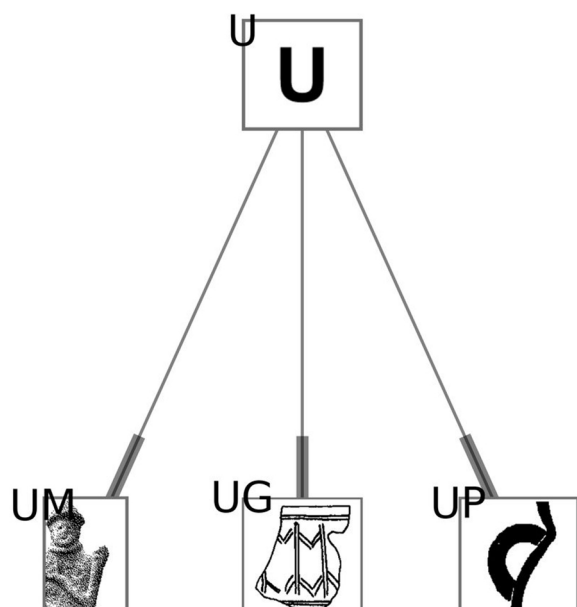


Figure 7. The upper part of the hierarchical typology (top of the tree) showing the three types of units used in the decomposition of decorations. The graph is handled with the library 'networkx', images with 'Image' and the spatialisation library is 'pygraphviz'.

on a ceramic. For example, there is only one 'neck', one 'base of neck', etc. (Figure 9).

Two particular UM need to be commented: 'high' and 'NA'. Ceramics are mostly surfaces of revolution rotated around the z-axis, meaning that most distinctive information of the ceramic surface will refer to the z-axis. The 'high' unit is useful when the rim is missing but the shard can be oriented; an identical solution would have to declare a 'down' unit. The 'high' unit allows us to recognise the top of the ceramic and gives information about the location of graphical units on the ceramic surface. The 'NA' unit (i.e. *No Data*) informs us about the entirety of the ceramic. When a ceramic has a 'NA' value, it is incomplete. The 'NA' unit permits us to control the 'edge effect' which appears for features

placed near the border of the region of interest (ROI); information on their neighbourhood is partly missing.

Plastic Units (UP)

Distinction between UM and UP is not necessarily evident. For example, carination could be considered as a plastic unit (UP) while handle could be considered as a UM. Therefore, the distinction between UM and UP is made according to whether it is possible to have more than one of these units on the ceramic. If so, units will be considered as UP (for example, 'handle' and 'hole'). Similarly, 'groove' could be considered as UG (Figure 10).

Graphical Units (UG)

As noted, UG's decorations are the most complex to individualise and record. The registration grid for the UG attributes present here is a balance between an explicit but long coding and a short coding with different rules of transformation (like translation, rotation and homothety). In most cases, we choose the second solution with a minimum of UG types, and a minimum of variables. We created one field for the UG typology (*Type*), one for its rotation (*Orientation*), one for its homothety (*Auto*), two for its translation in column and/or in line (*Nb_col*, *Nb_lin*), and three to record the missing data of its homothety (*Incomp_Auto*), of its translation: in column (*Incomp_Col*) and in line (*Incomp_Lin*). These latter fields are set to 1 when part of the graphic information is lacking.

Description of the UG's variables

Two contiguous UG are said to be different when they have, at least, a different value in one of these fields: *Type*, *Orientation*, and *Auto*.

Type

Graphical units (UG) are divided into two main categories: geometrical, the most common (Figure 11), and figurative (Figure 12).

```

1      definition={ U:"unit",
2                  UG:"graphical 'U'",
3                  figurative:"figurative 'UG' ",
4                  zoomorphic:"'figurative' representing an animal",
5                  quadruped:"'zoomorphic' with 4 legs",
6                  horse:"'quadruped' having a horse shape"}

```

Figure 8. Example of a 'horse' definition ('horse' sub-graph) in a Python dictionary called definition. A dictionary is composed by keys (left of the colons) and values (right of the colons). The definition dictionary is browsed and the text present in simple quotes (for example, 'U' at line 2) in the field value is recognised with Python's regular expression library ('re') and replaced by the value which has the same key. For example, the developed expression of horse is a 'graphical unit figurative representing an animal with 4 legs having a horse shape'.

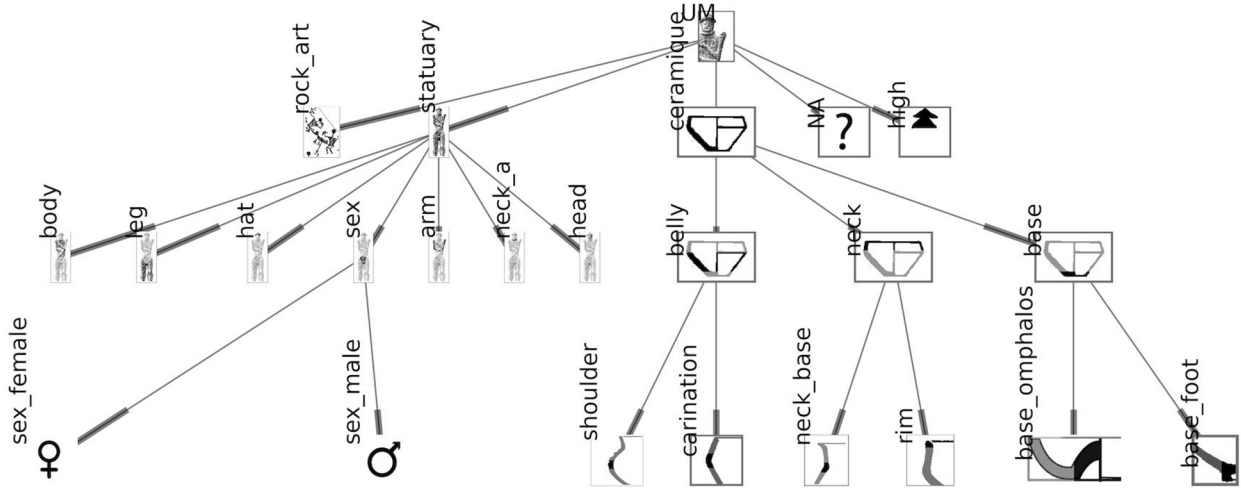


Figure 9. The UM subgraph. Each element is a specification of its predecessors. Here, for example, ‘rim’ and ‘base_of_neck’ are specifications of ‘neck’ because the ‘rim’ and the ‘base_of_the_neck’ belong to the morphological unit ‘neck’.

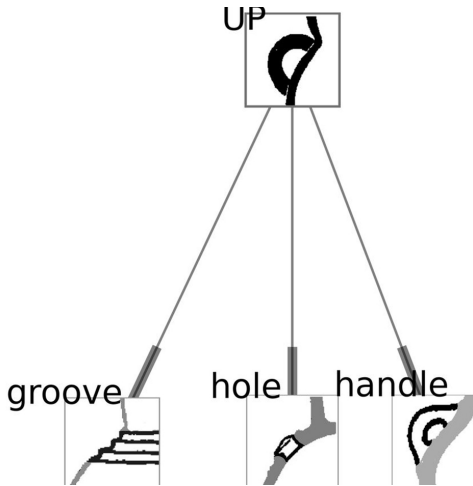


Figure 10. The UP subgraph.

At the same level in the typology tree (i.e. family intra-variability), distances between UG are calculated taking into account presence/absence of attributes (for ‘anthropomorphs’: position of arms, head, etc.), addition of colours, technique (adjunction, impression, etc.), etc., using Factorial Analysis (FA) or MultiDimensional Scaling (MDS). With the ‘figurative’ and ‘geometrical’ subgraphs, a third one, called ‘other’, has been created to record particular cases: ‘vacuum’ (empty), ‘undeterm’ (undetermined, unsolvable), ‘to_determ’ (undetermined, potentially solvable). A ‘vacuum’ is recorded between two or more UG when there is a surface that remains empty despite a sufficient area to draw one of the contiguous UG; ‘undeterm’ and ‘to_determ’ are useful for the (probable) corrections.

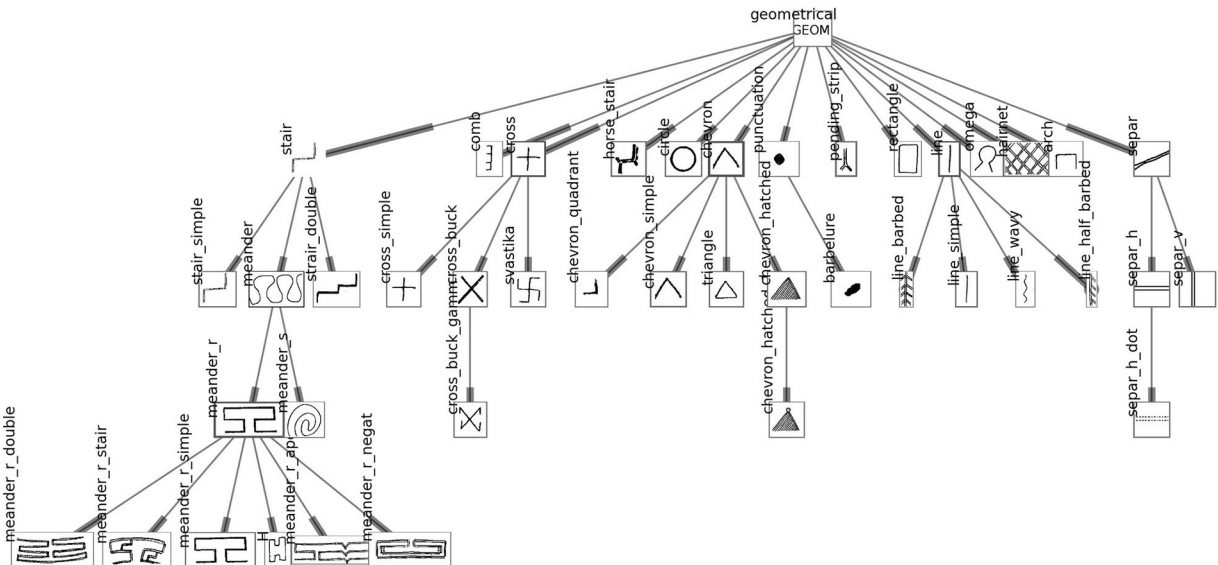


Figure 11. The ‘geometrical’ subgraph (subgraph of UG).

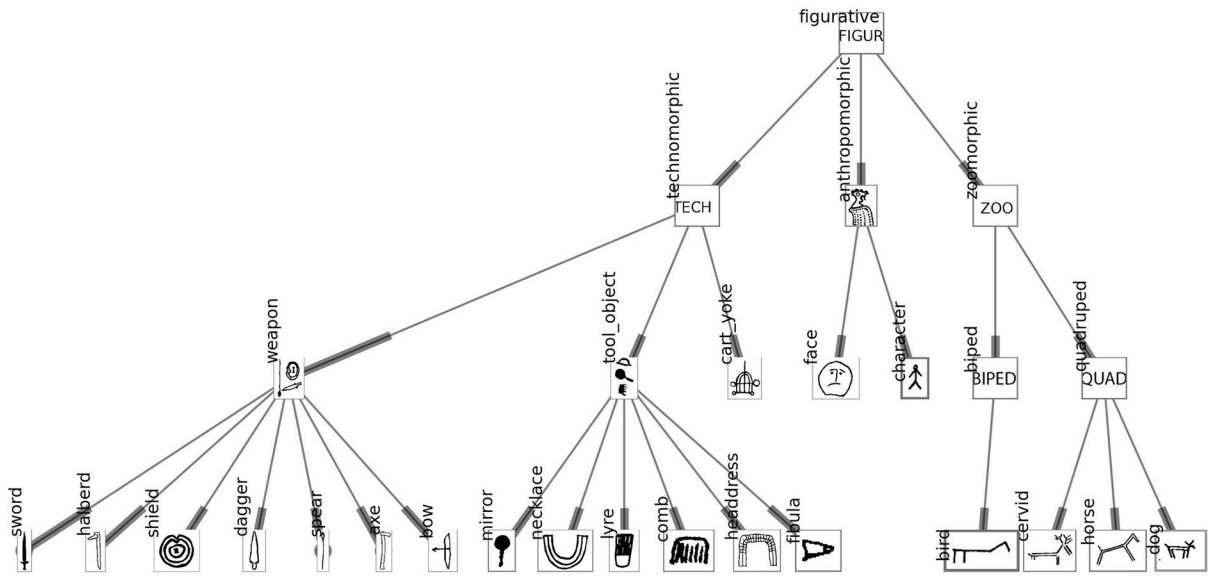


Figure 12. The 'figurative' subgraph (subgraph of UG).

Orientation

Synonym: rotation.

The default orientation of a graphical unit is given in the typology tree. Each quarter of rotation (clock rotation) is indexed by a different integer from 0 (default orientation) to 3 (oriented to the left) passing through 1 (turn to the right) and 2 (turn downwards).

Auto

Synonyms: homothety, change of scale, nested.

When a figure is repeated with amplification/reduction, and a low translation, the number of these amplifications/reductions is recorded in the field *Auto*.

Matrix variables (nb_col × nb_lin)

Synonyms: repetition by translation.

Two columns record the translation process: *Nb_col*, *Nb_lin*. When an UG is repeated various times, in column or in line, the number of repetitions is recorded in a matrix. By default a single UG has a 1 × 1 matrix.

Equivalent cases

When geometrical graphical units are contiguous, figure determination can be ambiguous (Van Berg, 1994), and therefore there can be several ways to register them (Figure 13). For those cases, when two or more coding could define the same figures, classes of

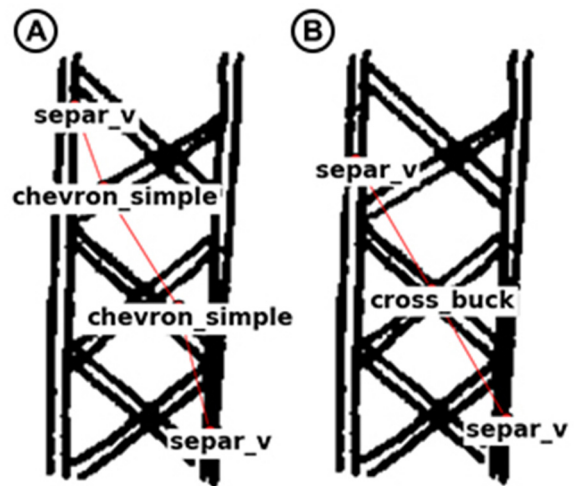


Figure 13. Two ways (A and B) to code differently the same pattern of UG. A: two columns of three 'chevron_simple', the first turned to the left, the second turned to the right; B: a column of three 'cross_buck'.

equivalence are recorded in the Python script and read during the graph analysis (Figure 14).

Study of composition

As already noted, combinations (patterns, figures, etc.) and locations (near the rim, above the carination, etc.) of units are not recorded with a priori qualitative categories, but recovered after the analysis of the spatialized graph. There is no need to present all

possible cases. Graph theory makes descriptions and categorisations unequivocal.

As an example, for the corpus of Mailhac I ceramics, scholars have recognised iconographic differences (graphical units and organisation of these units) between the decoration schemes of eastern and the western Languedoc (Carozza, 2000; Janin, 2009). The iconographic register of eastern Languedoc is particularly rich (*le registre iconographique est particulièrement riche*, Carozza, 2000, p. 11). To quantify precisely this ‘richness’, multivariate analyses performed on the ‘vocabulary’ (presence/absence, numbers or types of graphical units) and network indexes calculated on ‘syntax’ (spatial/topological

organisation of these units) will permit us to measure and compare ceramic decorations at the graph scale (Figure 15) or at the local scale (Figure 16).

As an example, to identify which UG are located above the ‘shoulder’ (a UM) on a decorated ceramic (Le Moulin’s tomb 142, here Figure 16), the following query is pasted to the application (Figure 17).

Conclusion

Ceramic decorations, as the most common elements of the symbolic subsystem (Renfrew and Bahn, 1991), have often been considered as privileged elements to the identification of cultural facies (definition of ‘style’).

A	B
1	<code>caseA_is_in_graph=False</code>
2	<code>caseB_is_in_graph=False</code>
3	<code>caseA=[('separ_v',0),('chevron_simple',1),('chevron_simple',3),('separ_v',0)]</code>
4	<code>caseB=[('separ_v',0),('cross_buck',0),('separ_v',0)]</code>
5	<code># case A</code>
6	<code>for typo_caseA, orientation_caseA in caseA:</code>
7	<code>for n in graph:</code>
8	<code>type_node=n['type']</code>
9	<code>orient_node=n['sens']</code>
10	<code>if typo_caseA == type_node and orientation_caseA == orient_node:</code>
11	<code>ct=ct+1</code>
12	<code>if ct == len(caseA):</code>
13	<code>caseA_is_in_graph=True</code>
14	<code>break</code>
15	<code>else:</code>
16	<code>ct=0</code>
17	<code>ct=0</code>
18	<code># case B</code>
19	<code>for typo_caseB, orientation_caseB in caseB:</code>
20	<code>for n in graph:</code>
21	<code>type_node=n['type']</code>
22	<code>orient_node=n['sens']</code>
23	<code>if typo_caseB == type_node and orientation_caseB == orient_node:</code>
24	<code>flag=1</code>
25	<code>ct=ct+1</code>
26	<code>if ct == len(caseB):</code>
27	<code>caseB_is_in_graph=True</code>
28	<code>break</code>
29	<code>else:</code>
30	<code>flag=0</code>
31	<code>ct=0</code>
32	<code># verification</code>
33	<code>if (caseA_is_in_graph and caseB_is_in_graph) == True:</code>
34	<code>print "Same pattern (group of UG) have been coded differently in the graph"</code>

Figure 14. Pseudo-Python code to recognise if the same pattern of UG has been coded differently for a given graph (see Figure 13 cases A and B). Firstly, we suppose that case A and case B do not exist in the graph (lines 1 and 2). Case A is declared as a Python list of tuples where the first variable of the tuple is the type and the second its orientation (lines 3 and 4). Both cases are researched in the graph by iteration on the nodes of the graph and lists of case A and B (lines 6 to 16 for case A and lines 19 to 31 for case B). When the same sequence is identified in the list and in the graph, the counter (ct) become equal to the length of the list and the value of the case is turned to True (lines 13 and 27). When case A and case B are both True, it means that the same pattern (group of UG) has been coded differently in the graph (line 34).

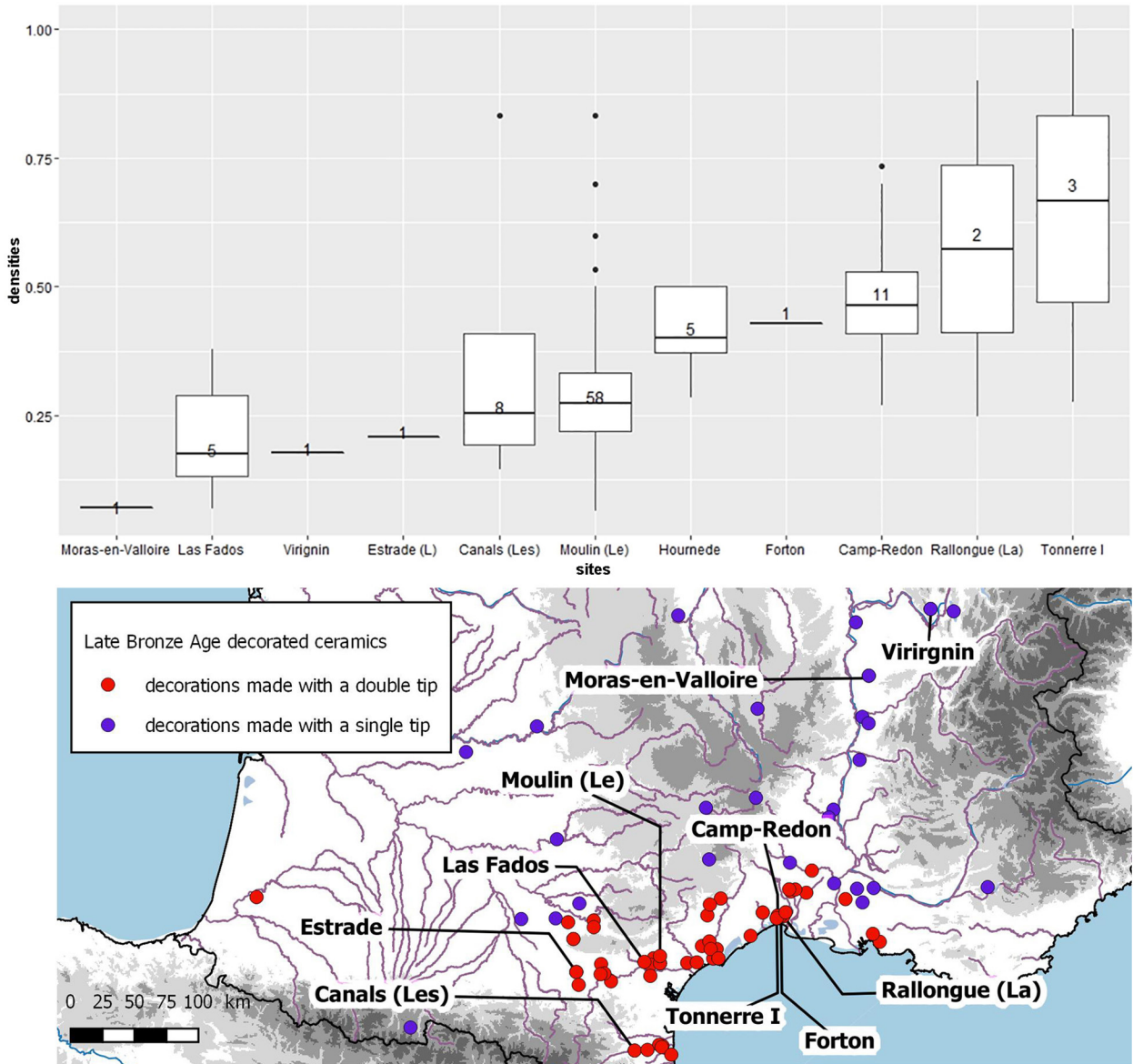


Figure 15. Boxplots of decoration densities for Mailhac I ceramics and locations of sites.

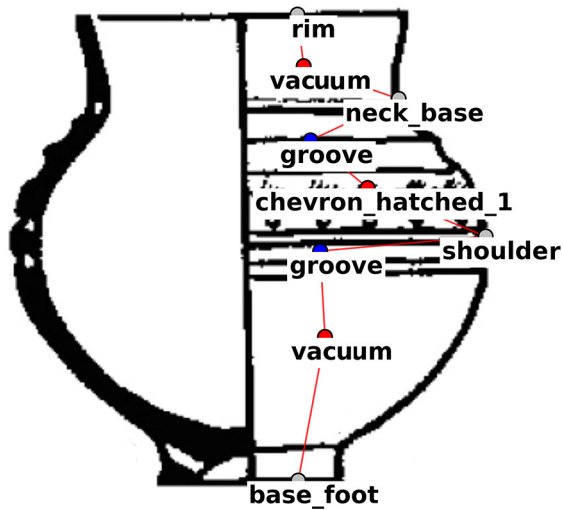


Figure 16. Geometric graph for the decorated ceramic from tomb 142, Le Moulin necropolis (Late Bronze Age). The 'chevron_hatched_1' frieze (1×20 by extrapolation from the drawing information) is located on the upper part of the ceramic; this means — in graph theory — that the frieze is in the topological subgraph of the 'rim'.

A	B
1	<code>for n in graph:</code>
2	<code>if n['type']== 'shoulder':</code>
3	<code>g.remove_node(n)</code>
4	<code>for sub_g in nx.connected_component_subgraphs(g):</code>
5	<code>for node in sub_g:</code>
6	<code>if node['type']=='rim':</code>
7	<code>for sub_node in sub_g:</code>
8	<code>sub_g(sub_node['up_the_shoulder'])=True</code>

Figure 17. Pseudo-Python code to recognise which UG are above the 'shoulder' of the ceramic. The graph *g* is divided into different connected components after the node 'shoulder' is removed (lines 1 to 3); as noted, it could only have one shoulder (a UM) by decoration. Each connected component is browsed (line 4). When a UG is recognised as the 'rim' or a 'high' in the component (line 6), the field 'up_the_shoulder' of the UG of the component is updated to True (line 8).

In Pre- and Proto-historic contexts particularly, only signifiers are conserved on the archaeological artefacts and the signified can only be supposed. Therefore, the first steps of iconography analyses have to be based on an analysis of the signifiers, considered as spatial sets of features, and should be closer to geometry than linguistics.

The CAA2016 session entitled 'Networking the past: Towards best practice in archaeological network science' has shown that graph theory, as a simple formal system, can be employed in numerous cases, but not always with particular relevance. For iconography and at the scale of the decoration's support, the interest of graph theory is to model the relationships (qualitative) when measures (spatial, quantitative) are difficult to calculate, mostly because of the contiguity of graphical units. More so, quantitative information (distances, azimuths, etc.) can be calculated within a GIS (spatialized networks) and recorded in the network (valued graph). The methodology briefly presented here opens possibilities of studying graphical systems with normalized indexes over a long period of time, on heterogeneous source data.

Acknowledgements

This project is supported by LabEx ARCHIMEDE from "Investissement d'Avenir" program ANR-11-LABX-0032-01. The author also wishes to thank Craig Alexander for help with English and constructive comments.

References

Carozza, L. (1997) *Habitats et cultures à la fin de l'âge du bronze en Languedoc et sur la bordure sud-ouest du*

Massif Central. PhD Thesis. École des Hautes Études en Sciences Sociales (EHESS), Paris.

Carozza, L. (2000) 'A la source du premier âge du fer languedocien', in Janin, T. (ed.) *Mailhac et le premier âge du fer en Europe occidentale. Hommages à Odette et Jean Taffanel. Actes du colloque international de Carcassonne, 1997*. Lattes: ARALO, pp. 9–23. Series: Monographies d'Archéologie Méditerranéenne 7.

Demoule, J.-P. (2009) 'Théories et interprétations en archéologie', in Demoule, J.-P., Giligny, F., Lehoërf, A., and Schnapp, A. (eds) *Guide des méthodes de l'archéologie*. 3rd edn. Paris: La Découverte, pp. 200–274. Series: Grands Repères.

Desenne, S. (2003) 'Décryptage d'un mode d'expression de la culture Aisne-Marne: élaboration d'une grille de lecture du décor céramique', in Buchsenschutz, O., Bulard, A., Chardenoux, M.-B., and Ginoux, N. (eds) *Décors, images et signes de l'âge du Fer européen. XXVI^e colloque de l'AFEAF, thème spécialisé*. Tours: FERACF, pp. 63–76. Series: Supplément à la Revue archéologique du centre de la France, vol. 24, n° 1. Available at: http://www.persee.fr/issue/sracf_1159-7151_2003_act_24_1 (Accessed: 31 March 2017).

Dietler, M. and Herbich, I. (1994) 'Ceramics and ethnics identity: ethnoarchaeological observations on the distribution of pottery styles and the relationship between the social contexts of production and consumption', in Binder, D. and Courtin, J. (eds) *Terre cuite et société. La céramique, document technique, économique, culturel. Actes des XIV^e rencontres internationales d'archéologie et d'histoire d'Antibes, 1993*. Juan-les-Pins: Édition APDCA, pp. 459–472.

Gallin, A. (2011) *Les styles céramiques de Kobadi. Analyse comparative et implications chronoculturelles au Néolithique récent du Sahel malien*. Frankfurt:

- Africa Magna Verlag. Series: Reports in African Archaeology 1.
- Gómez de Soto, J. (1993) «Pictogrammes», figurations anthropomorphes et zoomorphes sur les céramiques de la fin de l'âge du Bronze, une révision', in Briard J. and Duval A. (eds) *Les représentations humaines du néolithique à l'âge du fer. Actes du 115^e Congrès national des sociétés savantes, Avignon, 1990*. Paris: Editions du CTHS, pp. 149–162.
- Gómez de Soto, J. (2003) 'Oiseaux, chevaux, hommes et autres images. Les «signes» sur céramique en Gaule, du Ha A2/B1 au Ha D. Genèse, apogée, décadence et postérité', in Buchsenschutz, O., Bulard, A., Chardenoux, M.-B., and Ginoux, N. (eds) *Décors, images et signes de l'âge du Fer européen. XXVI^e colloque de l'AFEAF, thème spécialisé*. Tours: FERACF, pp. 11–25. Series: Supplément à la Revue archéologique du centre de la France, vol. 24, n^o. 1. Available at: http://www.persee.fr/issue/sracf_1159-7151_2003_act_24_1 (Accessed: 31 March 2017).
- Guilaine, J. and Py, M. (2000) 'Le Sud de la Gaule et les relations méditerranéennes et occidentales, Mailhac et le premier âge du fer en Europe occidentale', in Janin, T. (ed.) *Mailhac et le premier âge du fer en Europe occidentale. Hommages à Odette et Jean Taffanel. Actes du colloque international de Carcassonne, 1997*. Lattes: ARALO, pp. 415–432. Series: Monographies d'Archéologie Méditerranéenne 7.
- Janin, T. (2009) 'Jean Guilaine, Mailhac et le Mailhacien', in Traces Collectif (ed.) *De Méditerranée et d'ailleurs... Mélanges offerts à Jean Guilaine*. Toulouse: Archives d'Ecologie Préhistorique, pp. 353–364.
- Janin, T., Taffanel, O., and Taffanel, J. (1998) *La nécropole du Moulin à Mailhac (Aude)*. Lattes: ARALO. Series: Monographies d'Archéologie Méditerranéenne 2.
- Leroi-Gourhan, A. (1992) *Art pariétal. Langage de la préhistoire*. Grenoble: Éditions Jérôme Millon. Series: L'Homme des origines.
- Le Quellec, J.-L. (1998) *Art rupestre et préhistoire du Sahara. Le Messak libyen*. Lausanne: Payot. Series: Bibliothèque scientifique.
- Manen, C. (2000) *Le Néolithique ancien entre Rhône et Èbre: analyse des céramiques décorées*. PhD Thesis. École des Hautes Études en Sciences Sociales (EHESS), Paris.
- Mathis, P. (2003) 'Puissance et insuffisance des graphes pour la modélisation des réseaux', in Mathis, P. (ed.) *Graphes et réseaux. Modélisation multiniveau*. Paris: Hermès Lavoisier, pp. 19–48.
- Nicolas, A. and Comber, J. (2009) *Une écriture préhistorique? Le dossier archéologique de Moras-en-Valloire*. Pont-Saint-Esprit: La Mirandole.
- Renfrew, C. and Bahn, P. (1991) *Archaeology. Theories, Methods and Practice*. New York and London: Thames and Hudson.
- Sackett, J.R. (1990) 'Style and ethnicity in archaeology: the case for isochretism', in Conkey, M.W. and Hastorf, C.A. (eds) *The Use of Style in Archaeology*. Cambridge: Cambridge University Press, pp. 32–43. Series: New Directions in Archaeology.
- Tobler, W.R. (1970) 'A computer movie simulating urban growth in the Detroit region', *Economic Geography*, 46 (2) (Supplement: Proceedings. International Geographical Union Commission on Quantitative Methods), pp. 234–240. doi: 10.2307/143141.
- Van Berg, P.-L. (1994) *Grammaire des styles céramiques du rubané d'Alsace*. Zimmersheim: Association pour la promotion de la recherche archéologique en Alsace. Series: Monographie d'archéologie alsacienne 2.
- Zipf, G.E. (2006) *Studien zu den Anfängen figürlicher Darstellungen im Endbronze- und früheisenzeitlichen Frankreich und Italien. Motive, Dekorträger und Kontexte*. PhD Thesis. Freie Universität Berlin. Available at: http://www.diss.fu-berlin.de/diss/receive/FUDISS_thesis_00000002267 (Accessed: 5 April 2017).