Crystallography in Art & Archaeology

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acknowledgment:
P. Martinetto, J-L. Hodeau, M. Anne.

Néel Institute (formerly Laboratory of Crystallography)

P. Walter, J. Castaing, G. Tsoucaris, Le Louvre

www.neel.cnrs.fr
Past Employment

<table>
<thead>
<tr>
<th>Date</th>
<th>Employment Details</th>
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<tbody>
<tr>
<td>June 2009</td>
<td>NSLS II powder diffraction (US)</td>
</tr>
<tr>
<td>2001-2008</td>
<td>senior scientist fellowship (Néel Institute, FR)</td>
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<tr>
<td>1996-2000</td>
<td>powder diffraction (ESRF, FR)</td>
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<tr>
<td>1990-1995</td>
<td>high energy ion research center (GANIL, FR)</td>
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<tr>
<td>1988-1989</td>
<td>post-doc powder diffraction (SRS Daresbury, UK)</td>
</tr>
<tr>
<td>≤1987</td>
<td>graduated in Paris</td>
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</table>

Research

- powder diffraction (SRS, ESRF, SOLEIL, neutrons ILL)
- epitaxial thin films/multilayers of oxides (ferroelectric, relaxor, magnetic)
- cultural heritage (“SR/crystallography in Art and Archaeology”)
- colour fixing in analogues of Maya Blue and lacquer hybrid pigments
Diamond Light Source is pleased to announce their involvement in Artweeks, the Oxfordshire visual arts festival… Diamond continues to be involved in arts projects to demonstrate the links between science and art …

SOLEIL: the Heritage and Archaeology Liaison Office (HALO) provides support to access all the synchrotron beamlines of the facility.
One of the more unusual applications of the synchrotron is the study of historical artefacts, precious parchments and archaeological remains. X-rays offer a non-destructive means of uncovering a wealth of information about our past. Diamond will be able to help archaeologists, historians and museum curators to fathom out mysteries that lie behind the samples that they bring. How old are they? What is their exact material make-up? Where in the world do they come from? Are they authentic? What is written on them?

Research carried out at the synchrotron can also improve our understanding of the deterioration process of cultural heritage items, leading to more informed decisions about preservation so that our history can continue to be enjoyed by future generations.

Some of the first cultural heritage samples that have been brought to Diamond include fragments of the Dead Sea Scrolls, timber fragments from the legendary Tudor warship, the Mary Rose, and dinosaur remains from 68 million years ago.
• **Art/Science interface**: a long story where crystallography should play a central/leading role (societal impact)

>“The lack of communication between the sciences and the humanities — the "two cultures" of modern society — is a major obstacle for solving the world's problems”.


• **Name** Crystallography in Art and Cultural Heritage
• **Acronym** CrysAC
• **Chair** eric.dooryhee@grenoble.cnrs.fr

approved by the 21st IUCr General Assembly on 08/2008 (Osaka)

[www.crystallography.fr/crysac/](http://www.crystallography.fr/crysac/)
IUCr NewsLetter Vol. 16, No. 3 (2008)
Crystallography in Art and Cultural Heritage

CrysAC

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IUCr Newsletter Vol. 16, No. 3 (2008)

- To organize/coordinate a network of crystallographers and art specialists
- To promote the crystallographic concepts and techniques (not just as a tool) in this frontier field (cross-disciplinarity)

- art designers, artists, craftsmen, architects, art historians
- museum curators, conservators
- archaeologists
• Terms of reference: part 1

Many concepts (e.g. symmetry, patterning) are recurrently used in art and artefacts (paintings, sculptures, mosaics, textiles,...)

→ To analyze the fundamental crystallographic content in a work of art

→ To show how crystallography can be the basis for the creation of art (source of inspiration): patterns, sculptures, design in manufacturing based on atomic and molecular models (to help produce crystal structure-inspired art)

→ How does art provide some advanced support to crystallography, or graphically (2D, 3D) illustrate crystallographic ideas/models
• **Terms of reference : part 1 (cont’d)**

→ Safeguarding of crystal models, crystallographic displays: some crystallographic productions (2D or 3D patterns, structures) are inherently artistic and hence, have an enduring value as historical records in structural sciences (biology, chemistry, solid-state, …). To ensure care and maintenance of this “crystallographic cultural heritage“.

→ Educational purposes: promotion and teaching of Crystallography; elaboration of didactic material → an opportunity to illustrate and popularise the main crystallographic concepts to graduates and public
• **Terms of reference : part 2**

To implement advanced crystallographic methods (experimental and theory) to the analysis of artefacts

→ To consider crystallography as a powerful approach to all those (rarely trained in diffraction, symmetry and group theory) who are involved in the interpretation of artworks

→ To develop diffraction-based microanalysis and imaging, for diagnosis and identification of cultural and art objects (authentification, know-how of past societies, conservation)
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The XXV European Crystallographic Meeting
16-21 August 2009, Istanbul, Turkey.

Workshop: Symmetry and Crystallography in Turkish Art and Culture
Satellite workshop of ECM-25, Istanbul, 14-16 August 2009
jointly organized by MathCryst and CrysAC

Microsymposium: Crystallography in Art and Archaeology
Chairs: E. Dooryhée (FR) and P. Bezdika (CZ)

Programme: www.ecm25.org/
I  Analyses of symmetry patterns in art
II  Crystallographic studies of archaeological artefacts
III Analogies between crystal structures and art works
IV  Crystallographic “frustrations”


“Crushing one droplet of ink in the paper fold, there comes a symmetrical spot. Thus the repetition of anything is no longer anything. Going from the fortuitous to the rule.” Paul Valéry, Cahiers, 1894-1914.
Part I: PLANE SYMMETRY PATTERNS

"Symmetry is the concept by which man endeavours to grasp the order and beauty of phenomena. The basis of beauty and order derives from the fact that congruent repetitive elements build up the system in an orderly way...."

**Alhambra**, Granada: court of the Lions

This famous palace, residence of the Moorish Emirs (1231-1492), is one of the masterpieces of Islamic Art: ornaments, friezes and columns.

13 out of the 17 possible 2D periodic symmetry groups are realized in the Alhambra.
Mural mosaic in the Alhambra, 16th century (Granada).


Image courtesy of J-M. Castéra. www.castera.net
- *Mihrab* (محرrib pl. المحرراب)
- Decorations inside the Blue Mosque of Istanbul
- A Moorish *zillij* (tile pattern) from the Alhambra, 16th century
- Arabic calligraphy
- *Zillij* patterns, including a taqshir calligraphic border, 1325.

Kharaqan tomb towers, Iran, 1093 A.D.


Kharragán tomb towers, Iran, 1093 A.D.


J. Piaget: “A whole is not the same as a simple juxtaposition of previously available elements”. Structuralism, Paris 1968.
p4g : square lattice, and 1/8 of a square fundamental region of the translation group is a fundamental region for the symmetry group.
The requirement of a complete covering of the plane/space without gaps and overlaps leads to the magic numbers: 1, 2, 3, 4 and 6.

Due to this restriction, the number of different point groups is reduced:
- 2D: from $\infty$ to 10
- 3D: from $\infty$ to 32

There exist:
- 32 point groups
- 230 space groups
- ca. 600,000 determined crystal structures
- 85% are described by 6 space groups in 3D (3 in 2D)
- ca. 8,000,000 chemical compounds

→ the number of possible symmetries is small, the number of atomic motifs is nearly unlimited.
“The geometric rules simultaneously restrict and liberate the maker of tessellations. The (crystallographic rules) restrictions bring order and comprehension to a subject which defied and yet tantalised the artist; with comprehension comes the liberation of the imagination and the artistic skills to create tilings which appear impossibly complex”.


“Our pleasure in pattern, in symmetry, in order and its judicious breaking, provides gratification and reward, in relation with our system of perception, (re)cognition and creation”.

Geometric patterns (abstract ornamentations)
The fundamental region (the motif) is a geometric shape such as a polygon, displayed over an inactive background.

Figurative patterns (“zoomorphic”)
The fundamental region is a living form (plant, animal)

Crystallographic patterns
(crystal isomorphism)
constructed according to the principles of crystal formation, i.e. by close packing. The inner organisation recalls that of a crystal: space group, commensurable translations, motif.
Figurative crystallographic patterns
“To fit together congruent shapes I attempted to give forms of animals.... It remains an extremely absorbing activity, a real mania to which I have become addicted.... The silhouettes of birds and fish are the most gratifying shapes of all for use in the game of dividing the plane”.

M. Emmer. Frames from the movie « M.C. Escher : Symmetry and Space ». © Film 7, Roma.


<table>
<thead>
<tr>
<th>pmm</th>
<th>cmm</th>
<th>pmg</th>
</tr>
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<tbody>
<tr>
<td>p2</td>
<td>p4g</td>
<td>pgg</td>
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© David A Reid, Acadia University, Canada
http://plato.acadiau.ca/courses/educ/reid/Geometry/brick/
“and the reason that makes proportion please the Mind, is, that it saves it trouble, that it gives it ease, and that, so to speak, it cuts the work into halves. 

... every where that symmetry is useful to the soul, and can assist its functions, it is agreeable to it; but wherever it is useless to it, it is insipid because it takes away variety”.

Montesquieu ‘Of the Pleasures of Symmetry’ from an Essay upon Taste, in subjects of Nature and of Art, 1728.
Part II: CRYSTALLOGRAPHY and ARCHAEOLOGY

Ornaments from Mezin (23000 B.C., Ukraine)

See also http://members.tripod.com/~modularity/
1. Palaeolithic *Oldowan* (Homo Abilis 2.5 M-yrs)
2. Acheulean times (Homo Erectus, 1.5M-yrs)
3. Middle Palaeolithic (Levallois technique, 200k-yrs)
4. Upper Palaeolithic (Homo Sapiens Sapiens, 35k-yrs)

→ the earliest evidence of hominid technology (in the form of stone artifacts) with inherent symmetrical patterning

Statistical symmetry analysis in Anthropology & Archaeology: the frequency of occurrence (or extinction) of different basic symmetry patterns may be characteristic of a cultural community (CP = distinctive sign).

© Collections of the Logan Museum of Anthropology, Wisconsin, USA.
Traditionally patterned Javanese Batik cloths
Image courtesy of A. Haake.
Schematic representations of the seventeen two-dimensional patterns.
G. Pólya, Z. Krist. 1924

D. W. Crowe. Symmetries of Culture www.mi.sanu.ac.yu/vismath/crowe1/
Flow chart for determining the type of any of the 17 2-dimensional patterns

D.W. Crowe and D.K. Washburn. ‘Geometrical, Perceptual, and Cultural Perspectives on Figure/Ground Differences in Bakuba Pattern’.
#4 is a computed simulation by S.V. Jablan.

Top right: analogy with the polyethylene molecule 1D structure
Bottom right: analogy with the carbon nanotube 1D structure

M. Hargittai. ‘Symmetry, Crystallography, and Art’. International School of Molecular and Structural Archaeology, 2006.
PART III
Crystallography:
to analyse the structure and microstructure of ancient objects

Crystallographic data (phase and chemical identification, disorder and defects, grain size, texture,...) are viewed as a fingerprint of the history of the materials (provenance, manufacturing, ageing,...)
Lustres (9th c. Irak)
Courtesy of M. Vendrell (Barcelona)

XVIth c. fresco St Fiacre
Courtesy of S. Aze ©LRMH

Théorbe (16th c. Venitia)
Courtesy of J-P. Echard © Cité de la Musique

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Courtesy of S. Aze ©LRMH

Théorbe (16th c. Venitia)
Courtesy of J-P. Echard © Cité de la Musique
T. Ungár, P. Martinetto, G. Ribárik, E. Dooryhee, Ph. Walter. JAP 2002

The microstructure (size/strain: hand crushing, heating, sieving .... ) of the powder governs the diffraction peak profile = internal record of the history of the material ➔ modeling the diffraction line profiles of galena (PbS) in old Egyptian make-ups
The lead white PbCO$_3$ + 2PbCO$_3$·Pb(OH)$_2$
Coll. Ph. Walter, E. Welcomme, Applied Physics 2006

- cosmetics ($\geq$ 500 yrs B.C.)
- make up, face cream (Renaissance)
- cream, unguent, plaster
- easel painting (< XIXth c.)
- industrial painting (> XIXth c.)

Venetian cerussa

- cerussa from Antwerp (Rubens, Vermeer…)
- cerussa from Spain

fine, bright, immaculate, smooth coating,
fast drying, opaque, resistant, no browning…

Mathias Grünewald
Isenheim Altarpiece
(1512-1515-16)
© Colmar Museum
lamellar structure …BAABAA…

AA = rigid framework: PbCO$_3$-PbCO$_3$ bilayer as in macphersonite, plumbonacrite, leadhillite, susannite…

B = statistically disordered Pb(OH)$_2$ layer
(Pb2 1/6 occupancy)

*Ab initio* powder structure solution of "lead white" 2PbCO$_3$·Pb(OH)$_2$

ESRF-ID22: experimental set-up coupling XRD-XRD-XANES - X-ray micro-beam
Layer 1: calcium carbonate preparation layer; Layer 2: priming layer made of lead carbonates (hydrocerussite and cerussite); Layers 3, 4, 5: green copper pigments in mixture with lead tin yellow 2PbO-SnO₂ and lead carbonates; Layer 6: organic layer, varnish.
Hydrocerussite

E. Welcomme, Ph. Walter et al.
C2RMF Paris Le Louvre

2D diffraction pattern

Quantitative Rietveld analysis
(average composition: calcite, lead white)
E. Welcomme, Ph. Walter et al. C2RMF Paris Le Louvre

a few crystallites of cerussite in hydrocerussite

2D diffraction pattern

Quantitative Rietveld analysis
(average composition: calcite, lead white)
E. Welcombe, Ph. Walter et al.
C2RMF Paris Le Louvre

a few crystallites of cerussite in hydrocerussite

→ results depend on beam size (sampling, averaging)

2D diffraction pattern

Quantitative Rietveld analysis
(average composition: calcite, lead white)
Hydrocerussite : 73 %
Cerussite : 12 %
Stibnite : 15 %

Hydrocerussite : 52 %
Cerussite : 48 %
Phase diffraction mapping of a Roman fresco

- pigment recognition
- reconstruction of the image

grazing incidence diffraction

$\lambda = 1\text{Å}, 0.1 \times 1 \text{mm}^2, 40 \text{sec/image (« single bunch » mode)}, 4000 \text{ images}, 10 \text{ Gb}$

ID11  ESRF semi-quantitative Rietveld analysis of every diagram = $f(x,y)$
Scanning μ-XRD
E. Dooryhée et al.
Appl. Phys. A 2005

a - Cupid’s face
b - coarse Ca (plaster) + Q
c - Calcite white pigment
d - Fe Haematite
e - Fe Goethite (shading)
f - Cu Egyptian Blue
g - Pb(Mg)CO3 (+ PbO)
h - fluorescence PIXE map
i - diffraction map
j - reconstruction
Part III:
Analogies between crystal structures and art works.


e.g. see also ACA annual contest (2005) on ‘visual art depicting crystallography topics’
L. Bragg in “The souvenir book of crystal designs”, Festival of Britain, 1951.

“When in 1922 I worked out the first crystal of any complexity that had been analysed, aragonite, I remember well how excited my wife was with the pattern I showed her as a motif for a piece of embroidery....”

www.peterhugomcclure.com/htms/main.htm
Left: Azerbaijan/Turkish common ornament of 18th century A.D.
Right: structure of Quartz

Left: Buckminster Fuller’s geodesic dome, the U.S. pavilion at the World’s Fair, Montreal 1967

- An archway in the Sultan's Lodge in the Green Mosque, Bursa, Turkey 1424 A.D.
- Girih pattern from the Seljuk Mama Hatun Mausoleum in Tercan, Turkey 1200 A.D.

Escher’s discovery of polychromatic symmetry years before this notion appeared in the literature.


© M.C. Escher Co. B.V
Left: *Cubic Space Division*, lithograph, 1952. © M.C. Escher Co. B.V

Right: Ge crystal structure from H. P. Singh, *Acta Cryst.*, 1968

“The scaffolding represents a crystallographic group. It is like a dead body without a soul... Only after putting back the atoms does the fascination of a crystal reappear.”

orthorhombic Pmm2

Left: POV Ray reproduction of "cubic space division" by M.C. Escher, 1952. © Friedrich A. Lohmueller, 2000

Right: Depth, woodcut, 1952. © M.C. Escher Co. B.V.

Stars, wood engraving, 1948. © M.C. Escher Company B.V

“2 universes in coexistence: the Platonic Universe of the regular solids and the biological Universe of living forms and activity, the one coldly beautiful, perfect, rigid, static and eternal; the other messy, opportunistic, flexible, dynamic and evolving”.
Left: *Stars*, wood engraving, 1948. © M.C. Escher Company B.V

Right: C. Dejoie, E. Dooryhee, P. Martinetto. ‘Hybrid analogues of Maya Blue’
ESRF Newsletter “Art and Science”, 2006

“2 universes in coexistence: the Platonic Universe of the regular solids and the biological Universe of living forms and activity, the one coldly beautiful, perfect, rigid, static and eternal; the other messy, opportunistic, flexible, dynamic and evolving”.

Left : *Development 1*, woodcut, 1937. © M.C. Escher Co. B.V

Right : HRTEM image of a crystal grain of hematite grown in olivine M. Gemmi, Università di Milano

Part IV : CRYSTALLOGRAPHY

SYMMETRY BREAKING

Van Gogh, *Still Life of Shoes*, Oil on canvas 1886, © Van Gogh Museum, Amsterdam
“A horror of the words law, order, symmetry, geometry; artists prefer harmony, beauty, style, rhythm, unity, although the true meaning of these words differs very little.

The essence of the hostility of art towards science lies in the conviction that a fully discovered law will introduce triviality into poetry”.


from M. Hargittai. ’Symmetry, Crystallography, and Art’. International School of Molecular and Structural Archaeology, 2006.

N. Bohr: ”The strength of Art lies in its ability to remind us of the harmonies unattainable by systematic analysis”.
Crystallography and visual arts

- Drawing
- Garden art
- Interior art
- Photography
- Computer art
- Plastic arts
- Architecture

Villandry castle, France, 1536
Crystallography and performing arts

- Music
- Theatre
- Cinema
- Dance
Crystallography and...

education
diffusion
legacy

- Literature
- Calligraphy
- Poetry
- Weaving
- Culinary art

Image courtesy of E. Angelini, Politecnico di Torino, Italy

Crystallography

"ars sine scientia nihil est"  (J. Mignot, 14th century)

Art  Senses
F. Morellet *Sphere in metals* 1968, © Grenoble Museum, France