

# Using Network Science to Discover the Grand Masters of the Florentine Renaissance

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## 1 Introduction & Method

Many are familiar with the *great masters* of Florence. The household names of Michelangelo, Botticelli, Raphael, and Da Vinci have enamored art consumers for over 500 years [1, 2]. However, less is known about the *grand masters* of Florence – those who trained the great masters or trained those who trained the great masters. Their pupilage ties, where one famous painter trains another, represent a key mechanism through which expertise and techniques were transmitted through generations. In order to better understand the antecedents and outcomes of these pupilage networks in the Florentine Renaissance we pose two questions: (1) what organizing principles explain the emergence of the pupilage network? and (2) which Florentine painters, through their position in the network, had the greatest impact on the Renaissance?

We used historical records [1, 2, 8] to construct the pupilage networks among notable Florentine Renaissance painters from the birth of Giotto (1276) to the death of Bronzino (1572), the period art historians mark as initiating the revival of classical principles. A set of “nodes” consisting of all notable painters [1, 2] living and working in Florence during this period was identified ( $N = 50$ ). Great masters were identified as those whose paintings received the greatest critical acclaim [4]. A directed network was constructed where links indicate pupilage ties from apprentice to master (see Figure 1).



**Fig. 1.** Master-Apprentice Painter Network of the Florentine Renaissance (1276-1572)

Two sets of analyses were conducted: (1) ERGM [3, 6] was used to determine the ordering principles, and (2) a Renaissance index (*R*-index) was constructed in order to

identity the painters most influential in training, directly or indirectly via the pupilage network, the great masters of Florence. The  $R$ -index,  $R_i$ , was computed for each node, estimating each node's generativity based on their closeness (or geodesic path distance), through directed pupilage ties, from all other painters in the network, and then weighting those pupils based on the relative success of their paintings [4]. For each painter  $i$ , the index  $R_i$  is defined as:

$$R_i = \sum_{\substack{k=1 \\ k \neq i}}^N \left[ \left( \frac{1}{d_{ki}^\alpha} \right) * S_k \right] \quad (1)$$

where  $i$  = master,  $k$  = pupil,  $N$  = number of nodes,  $d$  = distance, and  $S_k$  = success of the pupil  $k$ 's paintings.  $R_i$  was computed at  $\alpha = 1, 2$ , and 3.

## 2 Results & Conclusion

*Which network signatures explain the emergence of pupilage ties?* ERGM [3, 6] identifies four factors (see Table 1): (1) the master's birth year (being born 10 years later during the Renaissance period (1276-1572) increases the likelihood of a master training a famous apprentice about ten-fold), (2) the master's lifespan (for each additional 5 years the master lived, the chance of training a famous apprentice is reduced nearly 80%), (3) the presence of master hubs – the propensity for a few painters to attract a disproportionate number of apprentices [7], and (4) the absence of pupil hubs – the lack of propensity for pupils to seeks apprenticeship under multiple painters [7]. This model demonstrates excellent MCMC diagnostics and GOF. Two controls, edges and an undirected edg cov term reflecting whether or not the pupil was alive and at least 12 years old at the time of the master's death, are included.

**Table 1.** ERGM of Master-Apprentice Network of the Florentine Renaissance

ERGM Parameter	Estimate	SE	OR
Control: edges	-11.0300***	0.1409	0.0000
Control: "Alive Together" (edg cov)	4.5580***	0.7361	94.4433
1. "Master's Birth Year" (node cov)	0.0045***	0.0008	10.0450
2. "Master's Age" (node cov)	-0.0157†	0.0095	0.1969
3. "Master Hubs" (idegree1.5)	0.4514*	0.2171	1.5705
4. "Apprentice Hubs" (odegree1.5)	-1.4380**	0.5092	0.2374

Note: SE=Standard Error, OR=Odds Ratio. For interpretation, ORs for birth year converted to log odds of being born 10 years later, & master's age of living 5 years longer. †  $p < .10$ , \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ .

*Who were the grand masters?* In order to discover which painters had the greatest overall influence on the transmission of renaissance artistic ideals through their direct and indirect pupilage of famous appreni, we calculated a Renaissance ( $R$ -) index for each painter. Table 2 compares the top 6 painters identified by the  $R$ -index to the top 6 based on the critical acclaim of their paintings. The top 6 in each do not overlap. In short, the great masters were not the grand masters. Of the great masters, only 2 had a famous pupil (Botticelli & Andrea del Sarto) and those successes did not propel them to the list of top 6 grand masters. The grand masters who were uniquely influential in the production of great art and artists were: Verrocchio, Perugino, Ghirlandaio,

Baldovinetti, Piero di Cosimo, and Cosimo Rosselli. If an artist's level of success is determined by the extent to which they trained others that either went on to produce great art and/or pass their ideas down to other artists who did the same, we have a whole new perspective on what makes the "ideal Renaissance Man".

The metrics developed here are also relevant to contemporary teams. For instance, the field of sports analytics has been fascinated by players who are not the great masters of their sport but whose presence improves others. In basketball the "Battiere effect" is named in honor of Shane Battiere whose own statistics are not record setting, but who makes everyone else's better [5].

**Table 2.** Great and grand master painters of the Florentine Renaissance

Painter	$R\text{-Index } (\alpha = 1)$	$R\text{-Index } (\alpha = 2)$	$R\text{-Index } (\alpha = 3)$
<i>Great masters – 6 painters whose paintings have had the most success (in descending order)</i>			
Leonardo da Vinci	0.2513	0.0939	0.0470
Raphael	0.2293	0.0782	0.0386
Botticelli	0.1044	0.0705	0.0650
Michelangelo	0.2416	0.0829	0.0412
Masaccio	0.0466	0.0205	0.0200
Andrea del Sarto	0.2727	0.1206	0.0812
<i>Grand masters – 6 painters with highest R-index (in descending order)</i>			
Andrea Verrocchio	0.5010	0.3472	0.2901
Perugino	0.4168	0.2555	0.2003
Ghirlandaio	0.3898	0.2299	0.1800
Baldovinetti	0.3893	0.2041	0.1349
Piero di Cosimo	0.3566	0.1959	0.1480
Cosimo Rosselli	0.3456	0.1783	0.1282

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