

A User Study on the Visualization of Directed Graphs

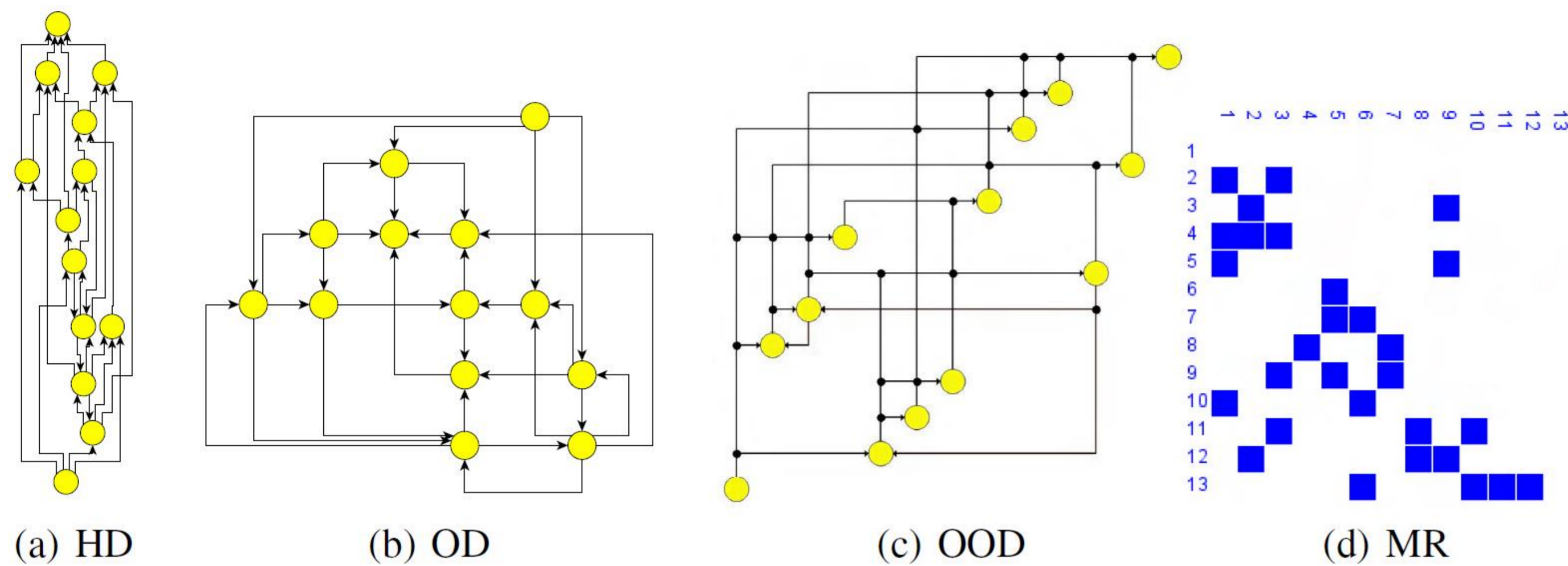
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Compared drawing styles for directed graphs

Overloaded Orthogonal Drawing (OOD) [2] is a recent graph visualization paradigm that resembles classical orthogonal drawings, but is specifically tailored to directed graphs of arbitrary vertex degree. Its properties suggest that it can be applied to perform visualization-based tasks more effectively than other related paradigms. We investigate the usability of OOD against other well-known visualization paradigms.



In a node-link visualization of a DAG it is desirable that edges flow in a common direction (say upward) according to their orientations, as in **Hierarchical Drawings (HD)** (see, e.g., [3]).

More general requirements are that the number of edge crossings, the number of edge bends, the drawing area, etc., are kept low. These are well addressed by **Orthogonal Drawings (OD)**, where edges are chains of horizontal and vertical segments (see, e.g., [4]). Unfortunately, OD algorithms do not control the flow of the edges in a desired direction.

Overloaded Orthogonal Drawing (OOD) merges and enforces the benefits of HD and of OD [2]. Indeed, edges are still represented using only horizontal and vertical segments, and if the digraph is acyclic, any directed edge (u,v) is drawn as an upward-rightward polyline consisting of one bend point. Also, edge segments can partially overlap to draw graphs with arbitrary vertex degree.

Moreover, a user study on undirected graphs [1] suggests that **Matrix-based Representations (MR)** are often more readable than node-link diagrams computed with force-directed algorithms.

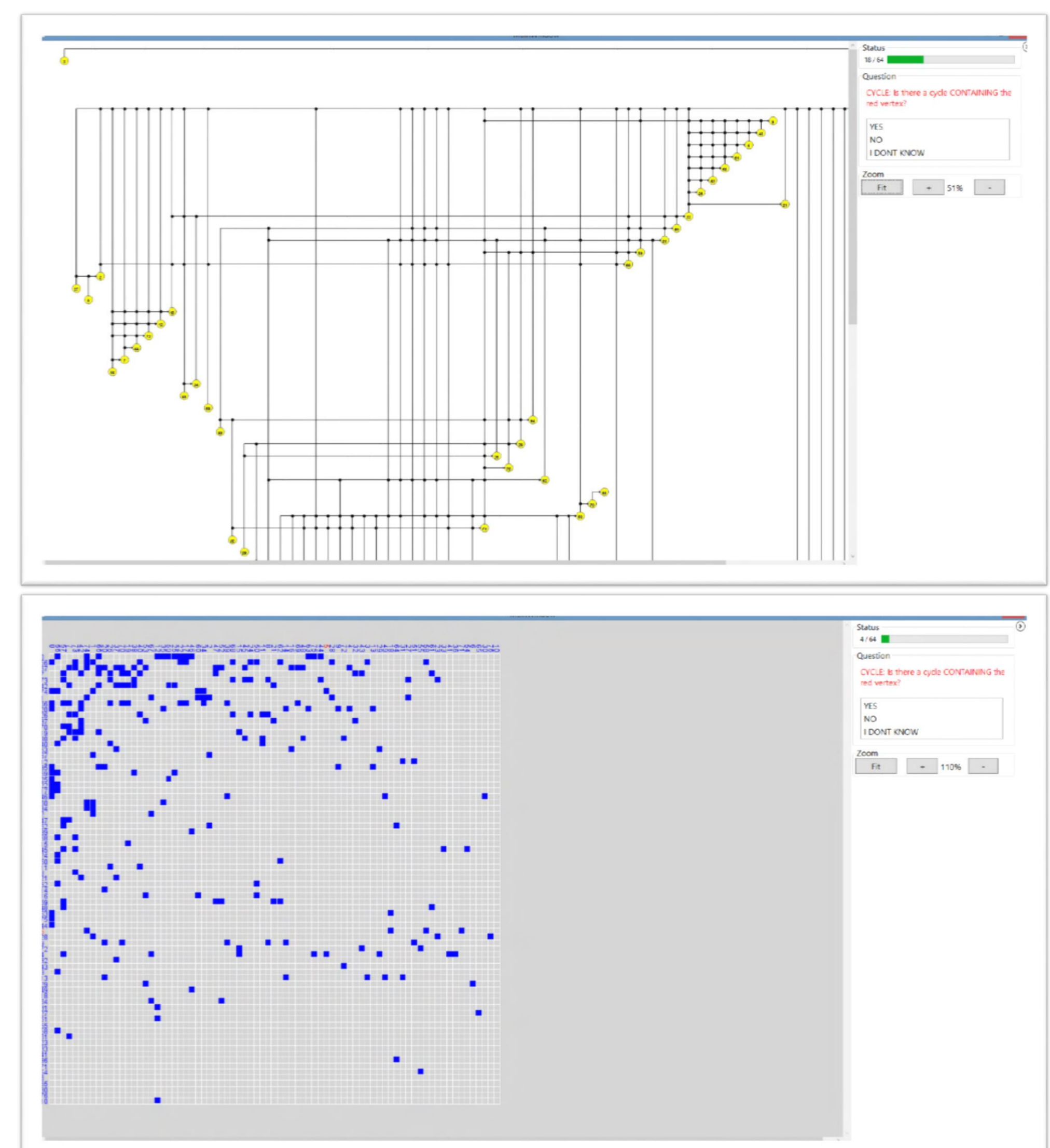
Experiments

The goal of our study was to address the following two research questions:

- **(Q1)** What is (among those considered) the most effective paradigm to represent directed graphs?
- **(Q2)** Are node-link diagrams more effective than matrix representations for depicting directed graphs?

We chose 4 different graphs, modeling both real and artificial networks, with and without cycles, with size (number of vertices) varying in the range [77,122] and density in [2.5,3.5]; for each graph we computed 4 drawings using the yEd Graph Editor implementations of HD and OD and our own implementations of OOD and MR. On each drawing the participants had to solve the following 4 tasks:

- **(PA)** "Is there a path between the two highlighted vertices?"
- **(DE)** "What is the out-degree of the highlighted vertex?"
- **(CA)** "Do the two highlighted vertices have any common adjacent?"
- **(CY)** "Is there a cycle including the highlighted vertex?"



Two screenshots of the user interface used for the user study

Results

We compared the performance of all the drawing paradigms in terms of **error rate** and **response time**. 21 volunteering students participated in the experiments. We performed a non parametric analysis whose results are summarized in the table below, which shows the mean values and the pairwise significance between each pair of drawing paradigms for error rate and for response time considering all the tasks (Overall) and single tasks.

The results show a clear advantage in terms of accuracy in the reading of the displayed graphs when using the OOD paradigm, over all tasks and in particular for the tasks involving paths (PA) and cycles (CY). In terms of response time, the user performances on the node-link representations (OOD, HD, OD) are comparable, although most tasks are executed slightly faster using HD. On the other hand, MR led to the slower response time values, except for the degree task (DE). In addition, the results reveal that node-link representations outperform the matrix-based representation, both in terms of error rate and response time, especially for task CY.

	Error rate					Response time				
	Overall	PA	DE	CA	CY	Overall	PA	DE	CA	CY
mean OOD	0.119	0.190	0.047	0.154	0.083	58	78	36	69	48
mean HD	0.199	0.250	0.142	0.190	0.214	55	69	41	55	56
mean OD	0.369	0.547	0.095	0.369	0.452	67	114	17	71	66
mean MR	0.423	0.559	0.047	0.285	0.809	129	187	27	145	158
OOD vs HD	.003	n.s.	n.s.	n.s.	.008	n.s.	n.s.	n.s.	.002	n.s.
OOD vs OD	<.001	.001	n.s.	.003	<.001	n.s.	n.s.	<.001	n.s.	n.s.
OOD vs MR	<.001	<.001	n.s.	n.s.	<.001	<.001	.001	n.s.	<.001	<.001
HD vs OD	<.001	.002	n.s.	.003	.001	n.s.	.003	<.001	.006	n.s.
HD vs MR	<.001	.001	n.s.	n.s.	<.001	<.001	.001	.001	<.001	<.001
OD vs MR	n.s.	n.s.	n.s.	n.s.	<.001	<.001	.002	.001	<.001	<.001

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