Visual Community Detection: An Evaluation of 2D, 3D Perspective and 3D Stereoscopic Displays

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Abstract. 3D drawing problems of the 90s were essentially restricted on representations in 3D perspective. However, recent technologies offer 3D stereoscopic representations of high quality which allow the introduction of binocular disparities, which is one of the main depth perception cues, not provided by the 3D perspective. This paper explores the relevance of stereoscopy for the visual identification of communities, which is a task of great importance in the analysis of social networks. A user study conducted on 35 participants with graphs of various complexity shows that stereoscopy outperforms 3D perspective in the vast majority of the cases. When comparing stereoscopy with 2D layouts, the response time is significantly lower for 2D but the quality of the results closely depend on the graph complexity: for a large number of clusters and a high probability of cluster overlapping stereoscopy outperforms 2D whereas for simple structures 2D layouts are more efficient.

1 Introduction

Long after the pionnering work of Kolmogorov [1], 3D drawings knew a phase of great interest in the mid-90's in the graph drawing community. Besides the beauty of the theoretical questions, this interest was mostly motivated both by the availability of new 3D display hardware, and by the exploration of new applications which emerged in particular in VLSI design (e.g. [2]). The most studied models included orthogonal grid drawings, convex and straight line drawings (e.g. [3], [4], [5]). And, the most common aesthetic criteria were the bounding area volume, the minimization of edge length and bends. NP-completeness proofs were deduced from 2D for the different criteria, and several theoretical bounds were highlighted in different cases. And, different algorithms and tools (e.g. GIOTTO3D, GEM-3D, 3D CUBE) were developed.

However, despite all these efforts, the 3D phase rapidely declined and it is sometimes considered as a prejudicial epiphenomenon in the graph drawing community (see Eades's invited talk at GD'10[1]). The main criticsm concerns the lack of layout lisibility often illustrated by the paradigmatic 3D drawing of K_7. Some

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[1] `http://www.graphdrawing.org/gd2010/invited.html`

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encouraging results for the multilayer layouts have nevertheless continued to punctually draw the attention. But as said by Eades they "use 3D with a 2D attitude"; the third dimension is added for representing a parameter (e.g. time).

Nevertheless, we believe that the 3D "trial" is essentially due to a non proper definition of 3D, and consequently to an inappropriate choice of the aesthetics. In the works previously quoted, 3D drawings are 2D representations of a perspective view, and the aesthetics are directly re-used from 2D without specific analysis of their adequation in 3D.

Recent cheap technologies offer 3D stereoscopic representations of high quality which allow the introduction of binocular disparities, which is one of the main depth perception cues, not provided by the 3D perspective. Stereoscopy may also be combined with virtual reality (e.g. [6]) but this approach is far beyond the scope of this paper. Although the general question of the benefits offered by stereoscopy over 2D still remains open, investigations on the 3D expressiveness are attracting a growing community of computer scientists (e.g. for an overview, [7]).

In graph drawing, recent works have shown the interest of stereoscopic 3D representations of node-link layouts of graphs for local analysis : in particular, [8] have experimentally confirmed the power of 3D, previously hightlighted by [9], to trace out short paths between close (distance 2 or 3) vertices in limited size graphs (with less than 150 nodes).

In this paper, we explore the relevance of stereoscopy for a higher level task: the identification of communities (i.e. vertex subsets strongly connected to each other) . This task is of great importance in the analysis of social networks where visualization knows an increasing interest. Most often, communities are first identified with a clustering approach for which various algorithms have been proposed (see [10] for a recent state-of-the art), and visual representations of clustered graphs are then used. But, the community detection suffers from a major problem: in many real life situations, communities do not form a non ambiguous partition of the graph and several overlappings are present. In order to tackle this difficulty, alternative strategies have been developed: e.g. give a particular place to some pre-defined vertices ("central actors") which are members of different communities ([11]), or duplicate vertices which belong to different communities (e.g. [12]). Other representations than node-link diagrams have also been proposed but we here restrict ourselves to the latter which is by far the most popular visual representation of social networks, and the only one to have been investigated in 3D.

Here, we do not propose an $n+1th$ strategy, but we analyse the resort to stereoscopy for detecting communities in a "crude" representation of the whole graph - obtained with the Fruchterman-Reingold algorithm. Roughly speaking, the question we are asking in our experiments is "How different is stereoscopic representation from 2D, and 3D perspective views for identifying communities in medium size graphs with different complexities ?" Beyond its popularity, the choice of the algorithm, which has been shown to be outperformed in 2D by other approaches, is here justified by two reasons: it directly computes a layout which highlights communities without pre- or post- processings, and it is directly applicable to both 2D, 3D perspective and stereoscopy which consequently limits bias in the comparisons. For pseudo-random graphs associated with different parameters such as the cluster size and the density of intra and inter cluster links, we conducted a user study: we asked participants the number of communities they could detect and we measured the time required to answer.

The rest of this paper is organized as follows. Section 2 briefly recalls some psycho-visual generalities on human 3D perception which guide our research. Section 3 details the experimental procedure for the comparisons. Finally, the results are analyzed in Section 4.

2 Stereoscopic Perception

We live in a 3D space and a long period of evolution has endowed us with organs that allow us to perceive a three dimensional space from visual information. A huge amount of research in cognitive sciences has been dedicated to the mechanisms implied in the perception of 3D environment (e.g. [13]). In addition to those associated with the shape and object detection, the biological mechanisms, which govern the perception of a distance in the optical axis -the depth-, play a crucial role. Depth perception is certainly a combination of several perceptive mechanisms, and various studies have been carried out in the last decades to try to measure the relative performance of different functions and visual cues used by the human brain to perceive depth (e.g. [14], [15], [16]). Roughly speaking, it seems that partial occlusion (an object partially in front of another one) is one of the most important factors whatever the distance between the person and the object. For limited distances (less than 40m), binocular disparities associated with stereoscopic vision and perspective motions also have an important effect, whereas for larger distances -not considered in this paper- other factors like aerial perspective come into play ([17], [18]).

The comparison of the relative effects of stereoscopy and motion cues is still widely discussed. They seem to be equivalent or complementary in various tasks (e.g. [19], [20]). More precisely, motion itself associated with a 3D perspective may give a faithful depth reproduction: object rotations jointly act with the spatial memory to form a 3D mental representation of the observed object ([15]). But motion is also useful both in perspective and in stereoscopy to detect objects hidden in a particular vision axis. Consequently, measuring the interdependence between these two cues is a very difficult task. This paper restricts itself to the comparison of stereoscopy and 3D perspective both combined with basic motion possibilities at a macroscopic level. However the analysis of the specific effects of motion are in our short term plans.

3 Experimental Design

Three viewing methods were employed during the experiment:

- 2D: a 2D graph layout was computed with the Fruchterman-Reingold algorithm and displayed on a 2D surface. The users were allowed to zoom in/out on the graph using the mousewheel and to apply a z-axis rotation on the layout by moving the mouse.
- 3D Perspective (3D persp): a 3D graph layout was computed with the Fruchterman-Reingold algorithm and displayed on a 2D surface with a perspective projection. Along with the zoom in/out and the z-axis rotation, the user was allowed to spin the viewpoint around the graph (x/y-axis rotation).
- 3D Stereoscopy (3D stereo): the same 3D layout with perspective projection as case 2 was used but with two viewpoints -computed in real time- to introduce the binocular disparity: one viewpoint for each eye, with a slight shift on the horizontal viewing axis to mimic the actual separation between the human eyes. The same interactions than in case 2 were allowed.

3.1 Apparatus

The visualization system ran on an Intel Core 2 Duo (3.00 Ghz) E8400 processor, with 4 GB of RAM and an NVidia Quadro FX 3800 GPU. All graphs were displayed in shades of white on a black background, using Gouraud shading (without projective shadows) and an anti aliasing algorithm to improve the quality of the display. The visualization was displayed on a white painted wall by an ACER H5360 3D projector ($2,30 \times 1,30$ m^2 screen) with a resolution of 1280×720 pixels (view angle of 0.05 degrees for a pixel in the center of the screen). Our system uses active stereoscopy with Nvidia 3D Vision Shutter glasses. By using these glasses we decrease the perceived luminosity. To avoid any bias and ensure the same level of luminosity for each viewing method, participants had to wear the glasses through all the experiment. Participants could also

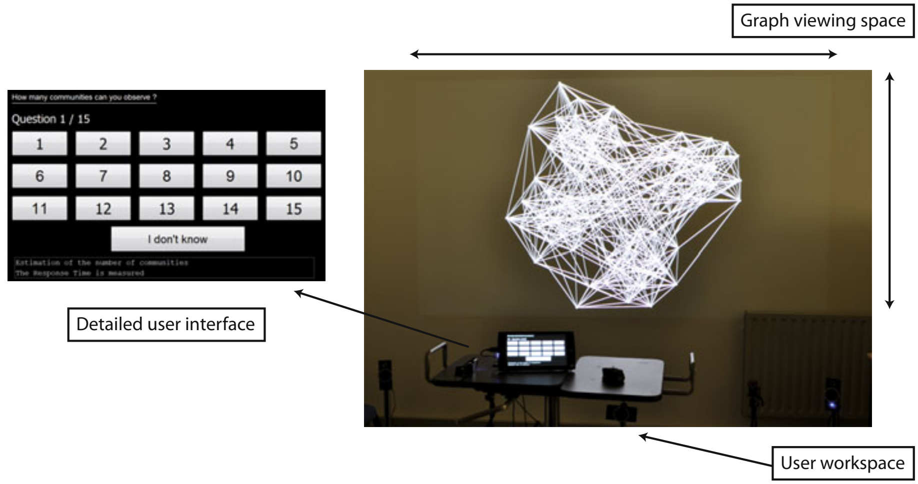

Fig. 1. Photograph of the experimental setup, along with a snapshot of the user interface of the tablet pc

interact with the system through a wireless mouse. The answers were entered using a touch screen tablet PC: different numbers were proposed (between 1 and 15, plus “don’t know”) and participants just had to touch the corresponding number. The experimental set up can be seen on Fig. 1.

3.2 Graph Database

In order to analyse the stereoscopic viewing for different topologies we have generated graphs with a classical pseudo-random model (e.g. [21]). The generic model $G\left(k, nv, \frac{p_{int}}{p_{ext}}\right)$ depends on four parameters: the number k of *a priori* clusters, the number of vertex per cluster nv, the probability p_{int} (resp. p_{ext}) of edge between two vertices belonging to the same cluster (resp. different clusters). We have generated 480 graphs with parameters ranges specified as $k \in \{4, 5, ..., 11\}$, $nv \in \{10, 20, 30, 40\}$, $\frac{p_{ext}}{p_{int}} \in \left\{\frac{0.02}{0.8}, \frac{0.02}{0.7}, \frac{0.03}{0.8}, \frac{0.03}{0.7}, \frac{0.03}{0.6}, \frac{0.04}{0.7}, \frac{0.03}{0.5}, \frac{0.05}{0.8}, \frac{0.05}{0.7}, \frac{0.05}{0.6}, \frac{0.065}{0.6}, \frac{0.07}{0.6}, \frac{0.1}{0.8}, \frac{0.08}{0.6}, \frac{0.1}{0.7}\right\}$. The parameters p_{int} and p_{ext} were empirically determined during a previous study by two confirmed users. Furtheremore, the largest graphs were discarded to avoid any performance issue. A few examples of such graphs are shown on Fig. 2.

3.3 Participants

35 participants (25 males, 10 females) carried out the experiment. Aged from 20 to 50, 30 of them were computer science students or researchers. Three of the subjects were left-handed with a right-handed use of the mouse. Only two subjects had never visualized any stereoscopic material, and eleven out of the 35 participants were not familiar with 3D software such as video games.

3.4 Experimental Procedure

To limit the experimentation duration, 15 layouts per viewing method were successively presented to each participant. To avoid any potential bias, the 3 viewing methods appeared in a random order (no interleaving). The 3×15 layouts were randomly picked from the database -without duplication within the same viewing method. This process aims at avoiding any learning bias in the community detection task. The maximal task completion time was 28 minutes (15 minutes on average).

Before the experiment, a few questions were asked to the participants to gather their experience with graph theory, graph visualization, stereoscopic displays and 3D software. A description sheet was handed out to briefly explain the experimental process, and a quick demo presented the three viewing methods with an easily readable graph (3 clusters, 20 nodes per cluster and a high p_{int} and small p_{ext}). Then, the participants had to go through a training session to get familiar with the system; the training session consisted in 3 layouts of increasing complexity for each viewing method.

Participants were asked to estimate the number of communities displayed as fast as possible, and told that the experimenter couldn’t help them. If a participant felt unable to detect communities, he/she was told to skip the layout

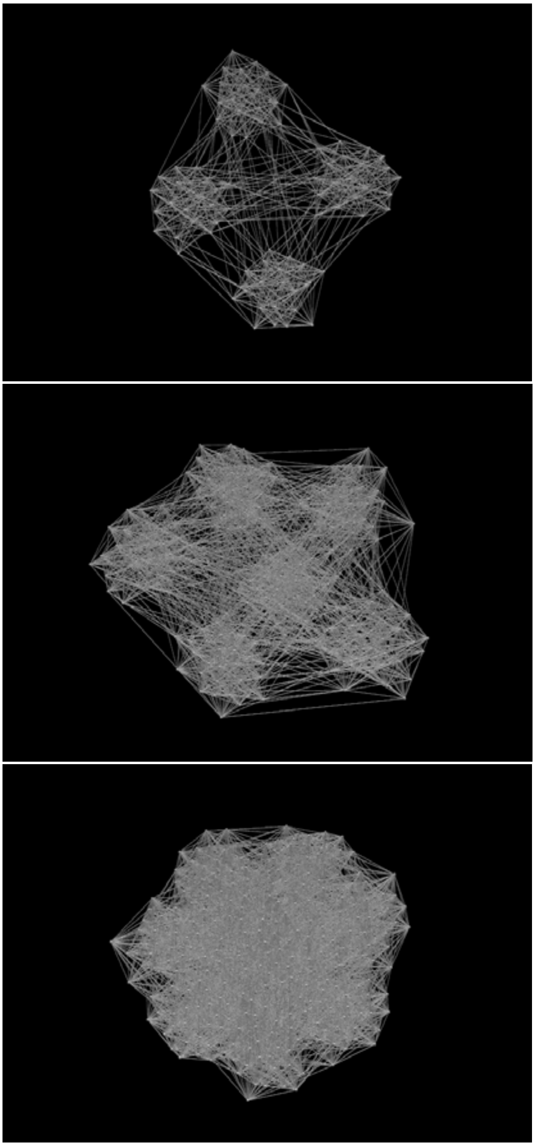

Fig. 2. Snapshots of the drawings of graphs of increasing complexity. $G_1 = G(k = 4, nv = 20, \frac{p_{ext}=0.05}{p_{int}=0.8})$; $G_2 = G(k = 6, nv = 30, \frac{p_{ext}=0.05}{p_{int}=0.7})$; $G_3 = G(k = 8, nv = 30, \frac{p_{ext}=0.07}{p_{int}=0.8})$.

by pressing a button labelled ”I don’t know”. Once all the layouts of a viewing method had been presented, the following method started with a notice of the experimenter (“you have finished the xth series, we move on to the next series”). At the end of the experiment, the participants were asked to state their visualization preferences (easiest and hardest cases), and their estimation (cases with the best and the worst performance).

4 Results

4.1 Quality of Community Detection

Let X be the set of answers given by all participants and I a subset of such that all the instances i of I share the same ratio range p_{ext}/p_{int}. Let I^i_{ans} be the number of communities proposed by a participant for an instance i, and I^i_{act} the *a priori* number of communities in the model (section 3.2). For each viewing method vm, $vm = \{2D; 3Dpersp; 3Dstereo\}$, the error is measured by the average of the differences :

$$Error_{vm}(I) = \frac{1}{card(I)} \sum_{i \in I} \left(\left| I^i_{ans} - I^i_{act} \right| \right)$$

Note that the answer “I don’t know” was counted as an error (i.e. the detection of only 1 community), and that for high values of p_{ext} and low values of p_{int} the term “error” is not perfect since the detection may be very ambiguous. But in these cases, the quality measurement of the community detection remains an open difficult question (see Fortunato, 2010).

The results depend on the complexity of the graph structuration here measured by the ratio p_{ext}/p_{int}: for small values, the communities are easy to identify, whereas for high values important overlappings and small community densities may make the detection difficult. Table 1 shows that 2D is significantly better for a small complexity (two way ANOVA: $p = 0.01$): communities are well-separated on the layout and are easily detected on a plane. For larger complexities, stereoscopy is slightly better (two way ANOVA: $p = 0.1$) in particular for large k

Table 1. Error for community detection. For each viewing method vm and for each interval of structure complexity (p_{ext}/p_{int}) I, mean error $Error_{vm}(I)$, along with the cardinality of each interval.

Complexity (p_{ext}/p_{int})	Cardinality	2D	3D persp	3D stereo
[0.02; 0.04]	369	**0.10**	0.37	0.27
]0.04; 0.06]	406	1.62	1.64	**1.40**
]0.06; 0.11]	405	3.27	3.22	**2.78**
]0.11; 0.15]	260	3.47	3.71	**2.99**

Table 2. Error for community detection. For each viewing method vm and for I, mean error $Error_{vm}(I)$ depending on k.

Complexity (p_{ext}/p_{int})	viewing method	$k = 4$	$k = 5$	$k = 6$	$k = 7$	$k = 8$	$k = 9$	$k = 10$	$k = 11$
$[0.02; 0.04]$	2D	0.0	0.0	0.1	**0.05**	**0.06**	0.16	**0.13**	**0.67**
	3D persp	0.0	0.0	0.13	0.08	0.25	0.35	0.37	1.56
	3D stereo	0.0	0.0	**0.0**	0.07	0.16	**0.11**	0.42	1.67
$]0.04; 0.06]$	2D	0.0	0.14	**0.0**	**0.19**	1.27	2.65	**3.35**	6.94
	3D persp	0.0	0.0	0.08	0.58	1.45	1.92	4.13	5.93
	3D stereo	0.0	0.0	0.13	0.9	**0.63**	**0.69**	3.81	**5.5**
$]0.06; 0.11]$	2D	0.0	0.0	0.5	1.35	2.24	3.95	6.15	7.9
	3D persp	0.0	0.13	0.32	**1.07**	**1.63**	4.44	6.12	7.61
	3D stereo	0.0	0.0	**0.21**	1.6	1.9	**3.42**	**5**	**6.88**
$]0.11; 0.15]$	2D	**0.28**	**0.88**	**2**	**4.69**	6.14	7.13	9	10
	3D persp	0.73	1.23	2.3	5.81	5.44	**6**	8.75	8.75
	3D stereo	0.93	1.35	2.06	4.75	**5.25**	8	**6.6**	**6**

Table 3. Standard deviation of the error for community detection for each viewing method and for a threshold of structure complexity (p_{ext}/p_{int})

Complexity (p_{ext}/p_{int})	2D	3D persp	3D stereo
< 0.06	1.28	1.16	1.67
≥ 0.06	3.63	3.69	3.38

values. Table 2 shows that for $k > 7$ stereoscopy is significantly better than 2D for a complexity greater than 0.06 (two way ANOVA: $p = 0.02$). The additional perceptive dimension combined with the motion seems to help to distinguish the aggregates even in presence of "noise" (overlappings). The situation is different for 3D perspective for which occlusions partly explain the debased results. Nevertheless, let us note that, whatever the viewing method, the error variation is important as soon as the complexity increases (Table 3). We have observed that this variation is similar for any value of k. Moreover, in our experimental sample group, it can not be explained by the non-familiarity with the 3D software but complementary experiments are required to reject this hypothesis.

4.2 Response Time

For each viewing method vm, the response time is the average time of response $Time_{vm}(I)$ of participants.

Table 4 shows that the response time for 2D is significantly smaller than for 3D whatever the graph complexity. And, the response times of 3D perspective and sterescopy are very similar. However, as discussed in the conclusion, a more precise analysis of the participant behavior (mouse motion) seems to establish that the time exploitation is different in the two cases.

Table 4. Response time for community detection. For each viewing method vm and for each interval of structure complexity (p_{ext}/p_{int}), mean time $Time_vm(I)$ in seconds.

Complexity (p_{ext}/p_{int})	2D	3D persp	3D stereo
$[0.02; 0.04]$	**7.3**	14.2	12.3
$]0.04; 0.06]$	**11.1**	17.9	17.7
$]0.06; 0.11]$	**12.4**	22.5	24.7
$]0.11; 0.15]$	**13.1**	21.9	21.1

4.3 Participant Perception

Table 5 underlines participant preferences for the stereoscopy, and difficulties felt with both 2D and 3D perspective. We are aware that a bias could exist: the experimentation by itself shows our interest in 3D to the participants who may be unconsciously inclined to share the researcher's enthusiasm. Nevertheless, part of the subjectivity is corroborated by the experimentations: among the participants who estimated that their best results were obtained with stereoscopy, 54% had their intuition confirmed by the results (whereas only 15.5% of them obtained their best results with the 3D perspective). Consequently, the "reject" of 3D perspective recalled in the introduction is verified. But, the comparisons show that this subjective perception is significantly different from stereoscopy.

Table 5. Subjective perception of the participants. For each viewing method vm, percentage of participants who answered that the case vm is the easiest (resp. the hardest) and the one for which they believe to obtain the best (resp. worst) performances. (NA: don't know)

Answer	2D	3D persp	3D stereo	NA
easiest	14.2	0	**68.6**	17.2
hardest	37.1	43	**5.7**	14.2
best performances	11.3	0	**74.3**	14.4
worst performances	43	34.3	**5.7**	17

5 Conclusion

As far as we know, this paper presents a pionnering research in the use of stereoscopy for a visualization problem which has known an increasing interest in the last decade: the detection of communities in large graphs. Our first experiments highlight an important difference between stereoscopy and classical 3D perspective which has been widely critized by the graph drawing community. Moreover, even if the debate remains widely open, experimental results seem to show the interest of stereoscopy against 2D for complex structures with numerous clusters of variable density and many overlappings. Obviously, additional experiments are needed to confirm these results on larger populations and real life databases; and to better understand the observed differences.

In the near future, our objective is to go beyond the measurement of errors by apprehending more precisely the role played by motion in 3D environment. To that aim, during the experiments we stored the mouse movements for each participant. A first superficial analysis highlights important use differences between 3D perspective and stereoscopy. This research could lead to investigating new optimization criteria in the graph drawing community which take into account not only the aesthetics of the layouts but also the handling for their interpretation and use.

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