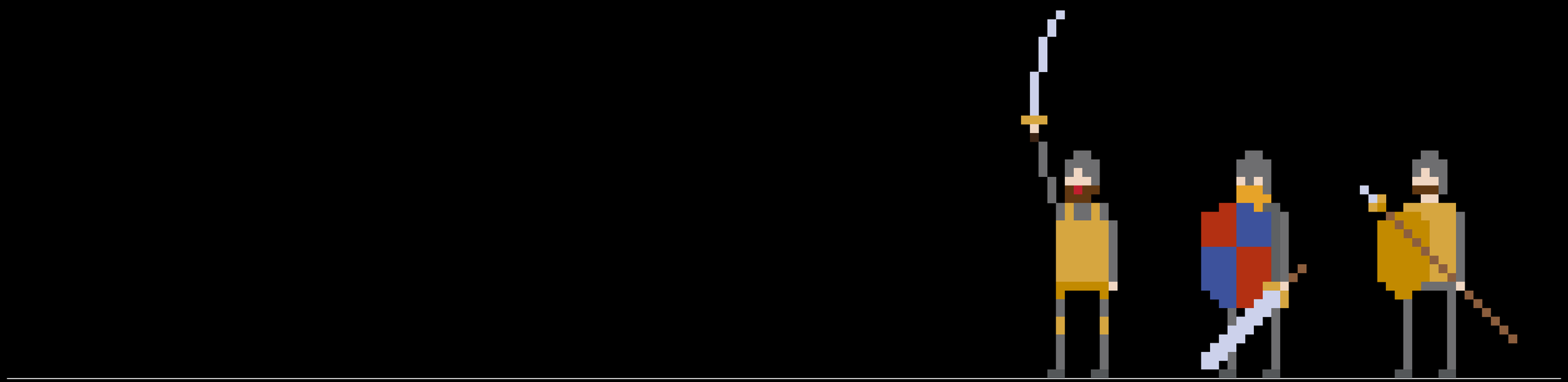
# Visualizing Player Interactions in Online Games



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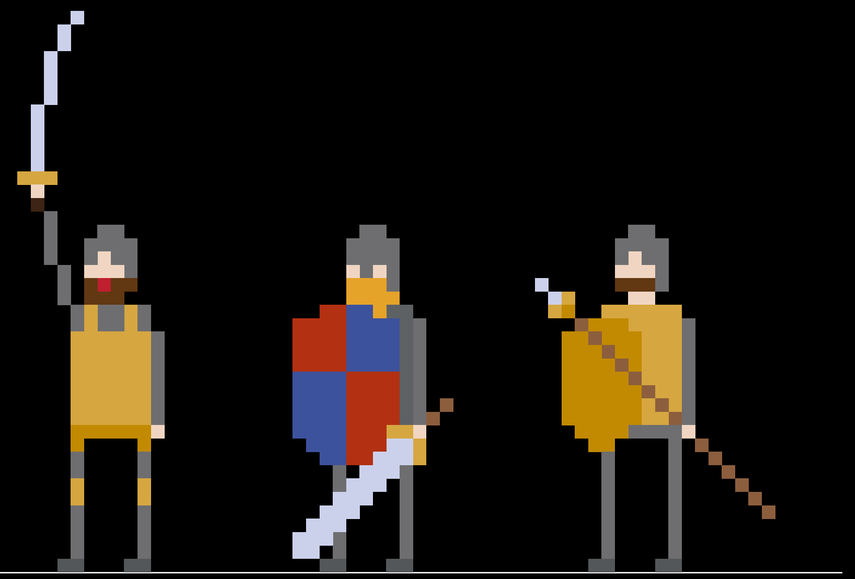
You can discover more
about a person in an hour
of play than in a year of
conversation.

– Plato



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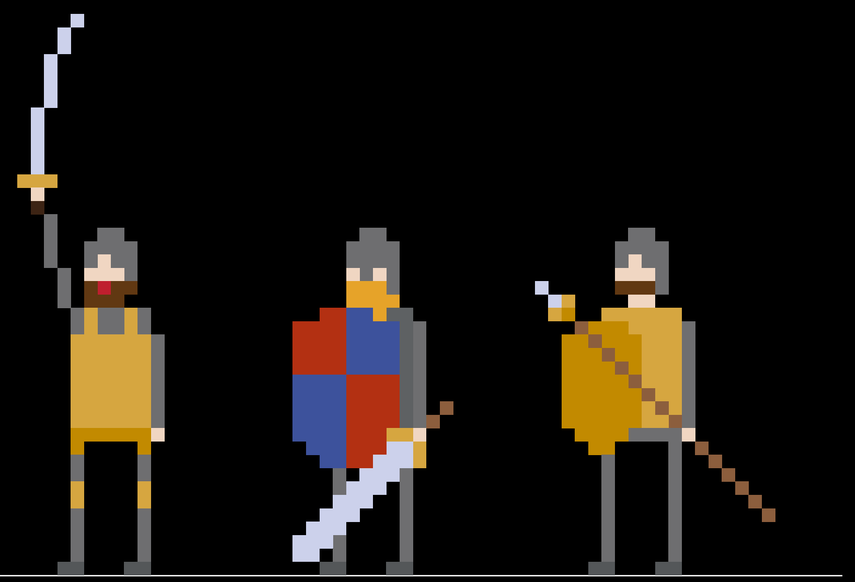
44% of the global internet population plays online games. In real terms, that is over 700 million people.

– Spil Games (2013)



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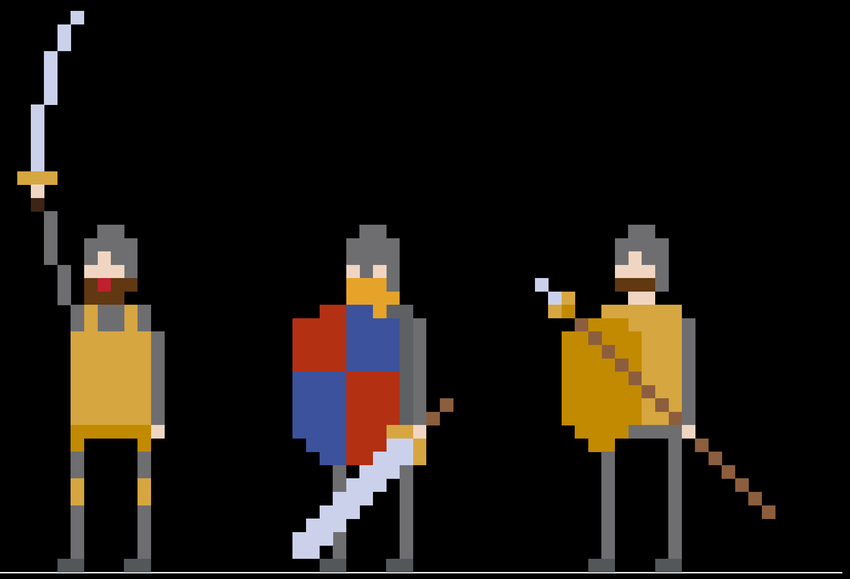
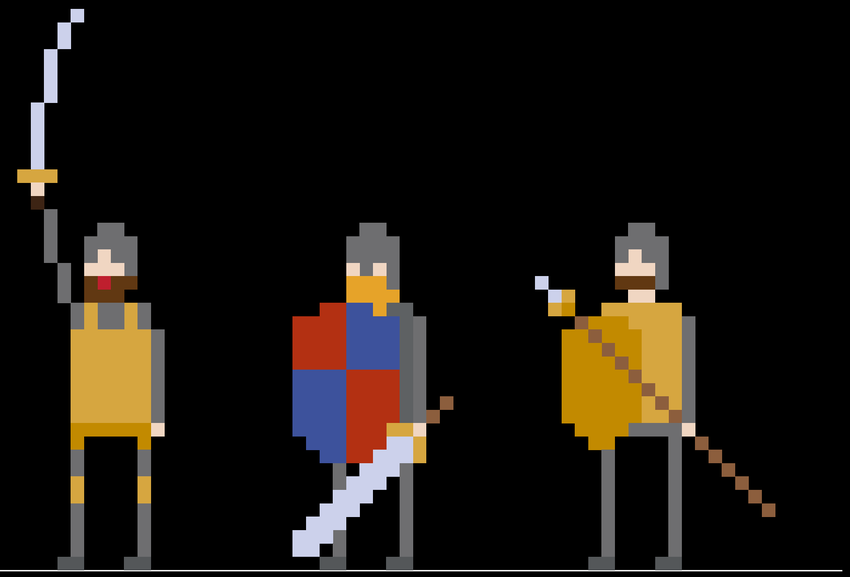
In the US, online gamers
spend 6.5 hours a week on
average playing with others.
– Polygon (2016)



Massively Multiplayer
Online Role-Playing Games
(MMORPGs or MMOs)

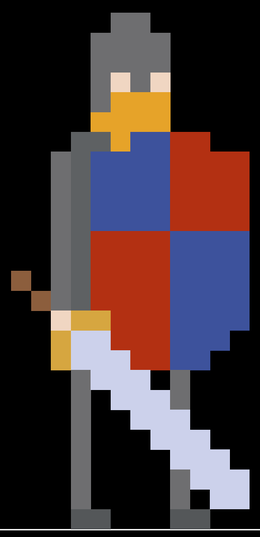


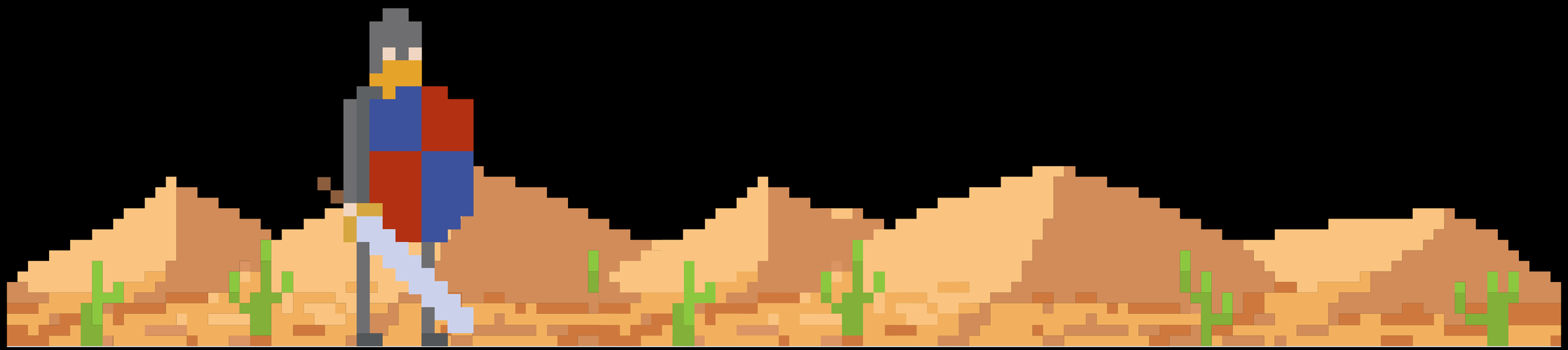
WORLD OF WARCRAFT

GUILD WARS 2™

ファイナルファンタジーXIV
FINAL FANTASY XIV ONLINE

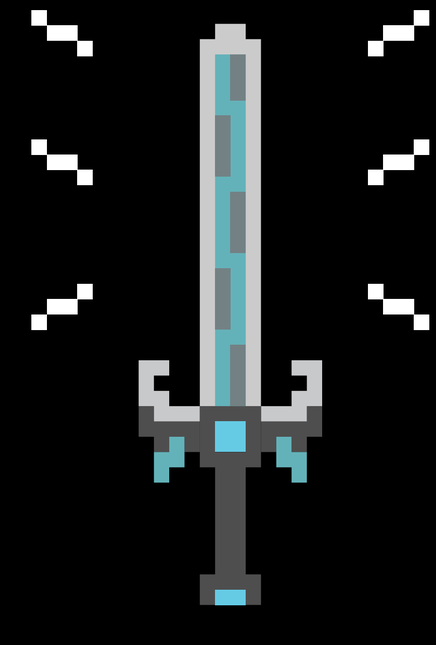
AION™



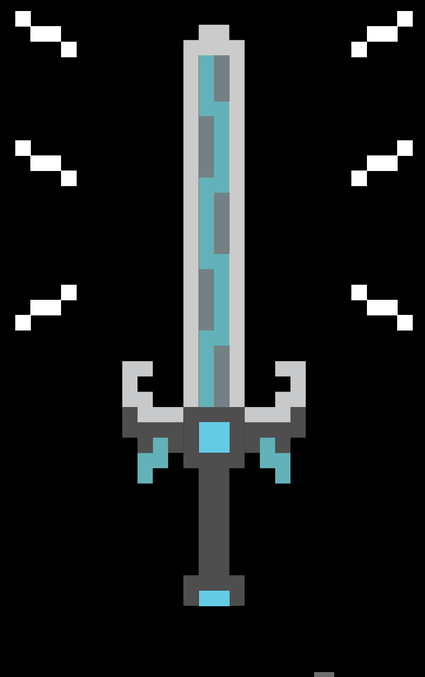


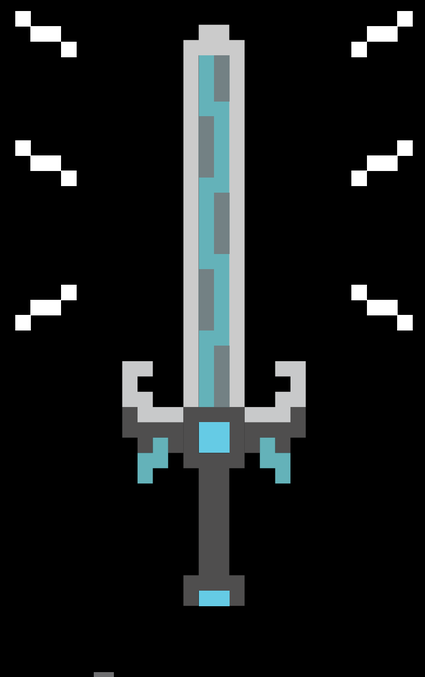

YO
SUP

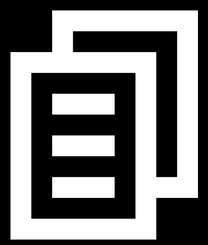

RAWR
DIE



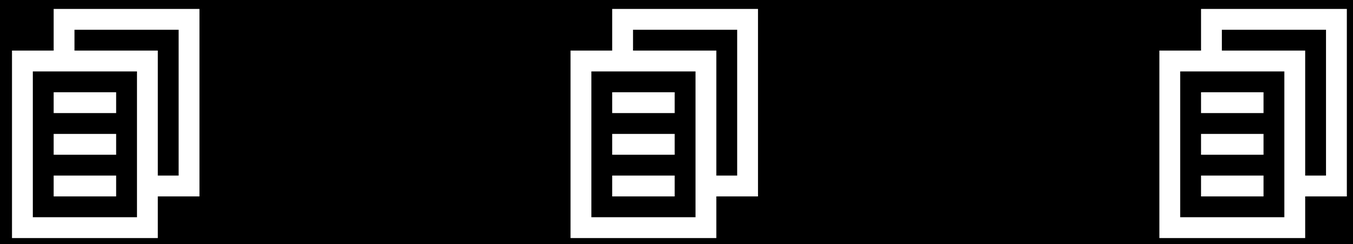

HUE HUE

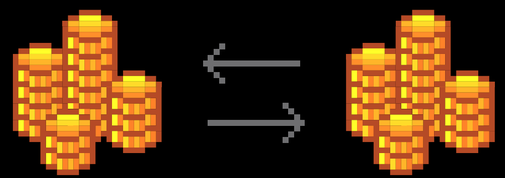






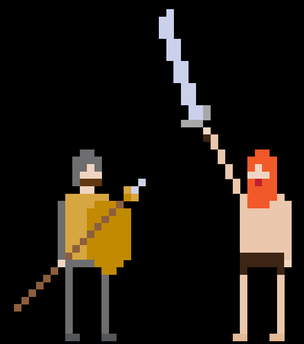
2017.03.31 22:35:34 : Critical Hit!Xalt-SL received 710 damage due to the effect of Flame Cage.
2017.03.31 22:35:34 : Xalt-SL blocked Branden-SL's attack with the protective shield effect.
2017.03.31 22:35:34 : Xalt-SL received 398 damage from Branden-SL.
2017.03.31 22:35:34 : You recovered 410 HP by using Absorbing Fury.
2017.03.31 22:35:34 : You recovered 743 HP by using Absorbing Fury.
2017.03.31 22:35:35 : Xalt-SL blocked LindWanijima-SL's attack with the protective shield effect.
2017.03.31 22:35:35 : LindWanijima-SL inflicted 488 damage on Xalt-SL by using Volley.
2017.03.31 22:35:35 : PvCuShee-SL inflicted 531 damage on LeonTyrron-SL by using Spread Shot.
2017.03.31 22:35:35 : LeonTyrron-SL became stunned because PvCuShee-SL used Spread Shot.
2017.03.31 22:35:35 : Xalt-SL blocked Looping-SL's attack with the protective shield effect.
2017.03.31 22:35:35 : Looping-SL inflicted 71 damage on Xalt-SL by using Chastise.
2017.03.31 22:35:35 : Xalt-SL blocked Looping-SL's attack with the protective shield effect.
2017.03.31 22:35:35 : LeonTyrron-SL is no longer staggering.
2017.03.31 22:35:35 : LeonTyrron-SL restored 1,914 HP with Splendor of Recovery.
2017.03.31 22:35:35 : Crowley-SL restored 820 HP with Splendor of Recovery.
2017.03.31 22:35:35 : MrPuddles-SL restored 1,562 HP with Splendor of Recovery.
2017.03.31 22:35:35 : Branden-SL restored 1,740 HP with Splendor of Recovery.
2017.03.31 22:35:35 : Your Attack has been boosted by using Berserking.
2017.03.31 22:35:35 : Your Accuracy has been weakened by using Berserking.
2017.03.31 22:35:35 : Your Physical Def has been weakened by using Berserking.
2017.03.31 22:35:35 : Xalt-SL blocked Branden-SL's attack with the protective shield effect.
2017.03.31 22:35:35 : Xalt-SL received 85 damage due to the effect of Reroute Power.
2017.03.31 22:35:35 : Xalt-SL restored its movement speed.
2017.03.31 22:35:35 : Your movement speed is restored to normal.
2017.03.31 22:35:35 : Xalt-SL blocked LindWanijima-SL's attack with the protective shield effect.
2017.03.31 22:35:35 : LindWanijima-SL inflicted 488 damage on Xalt-SL by using Volley.
2017.03.31 22:35:35 : LeonTyrron-SL has transformed into Mau by using Transformation: Mau.





In-Game Gold Transactions


Private Messages



Skills and Damage

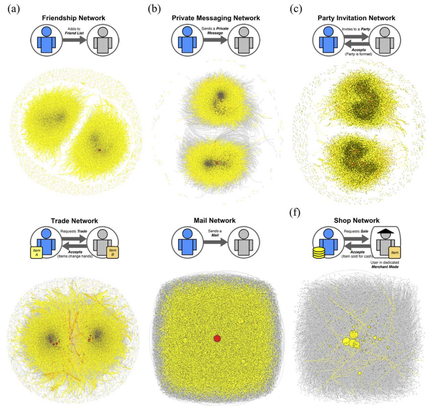



**Figure 2. The definition and the graphic representation of the six AION networks.** The Realm-vs-Realm design of AION where gamers belong to one of two tribes (Heavenly and Diabolical) that cannot communicate is evident in the existence of two similarly-sized large components. Red-colored nodes indicate exceptionally high-degree nodes.
doi:10.1371/journal.pone.0033918.g002

To characterize the structures of and correlations between the interaction network, we measured the following quantities [8]:

- The **node degree distribution**, one of the most basic network measures, is known to correlate with many (but not all) properties of the network. The degree (often denoted $k$) of a node is the number of nodes connected to it, called its neighbors. In directed networks as ours there are two degree types, the in-degree $k^{in}$ (the number of edges pointing at the node) and the out-degree $k^{out}$ (the number of edges pointing from the node). Also in a directed network, a connected node pair $(i,j)$ is called **reciprocal** if there exist edges pointing in both directions. The **reciprocity** of a network is the fraction of reciprocal node pairs among all connected node pairs.
- Two nodes are said to belong to the same **component** if there exists a path, a series of connected nodes, between the two. Networks typically exhibit a single predominantly large component called the Giant Connected Component (GCC). The length of the shortest path between two nodes is called the shortest distance between the two. The **diameter** of a network is the largest of the shortest paths.
- The **clustering coefficient** $C \in [0,1]$ is defined as the probability that two neighbors of a node are themselves neighbors, and thus represents the relative abundance of triangles in networks. More generally in a directed network a triplet of nodes can possess a richer structural details, and the **triad census** of the thirteen distinct configurations or motifs are often carried out [11,12]. The benchmark for the relative abundance or scarcity of a motif is, naturally, the null model (random graph). Specifically, the relative frequency of each the thirteen motifs against their expected number in the null model is quantified via the Z-score.





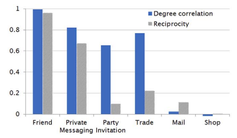



**Figure 3. The Pearson correlation coefficient between the in- and out-degrees of nodes (solid), and the reciprocity of edges in the AION interaction networks.** The four social-type networks (F, PM, PI, and T) can be further divided according to the reciprocity, the low value of which in Party Invitation and Trade interactions are believed to indicate significant strategizing in the latter two cases.
doi:10.1371/journal.pone.0033918.g003

means the buyer and the in-degree the merchant, the small correlation implies that there exists a strong tendency for role specialization among gamers into *magnate merchants* and others. A similar effect is present in the Mail network also: Mail is the only method of gamer-to-gamer communication that works offline, and from this we assume that a small number of gamers develop into high-volume mail senders (since we do not have access to the messages, at this point we were unable to discern the exact nature of high-volume Mailers.).

Our discussions thus far render the degree distributions, presented in Figure 4, straightforward to understand: First, the similarities between the in- and the out-degree distributions in the F, PM, PI, an T networks are consistent with the high level of correlation between the two. In Shop and Mail, the two are clearly disparate: in Shop, the "magnate traders" appear as the high in-degree nodes, while in Mail the high-volume mail senders are the high out-degree nodes.

## B. The Triad Census

As discussed earlier, the relative prevalence of each of the thirteen triad network motifs given in Figure 5 (a) tell us in more detail the interaction patterns in networks. For our AION networks, we show them in Figure 5 (b), in terms of both their fraction and the Z-scores assessed against the null model (Eq. (1), also see Tables S2 and S3). Interestingly, the Friendship, Mail, and Shop networks each show one predominant motif type: for instance, in Friendship network type 7 account for more than 90% of node triplet relationships, which can be attributed to the highly reciprocal nature of the interactions. The opposite reasoning can be applied to Mail and Shop: low reciprocity reflects again the existence of high-volume senders and magnate traders. Comparing the prevalence of motifs against the null models allows us to detect signals discounted by random expectations, and this is done via Z-scores (Eq. (1)). This is particularly necessary and illuminating in the cases of the other three networks (Party, Private Messaging, and Trade), since by considering the null models we can see that even though multiple motifs can be similarity abundant (Figure 5 (b)), some can be over- or under-represented in a significant manner, as we see in Figure 5 (c). Finally, we note that the overrepresented ones (i.e., ones showing positive Z-scores) are the closed triangle ones in all these network, reflecting the relatively high clustering tendencies in the social-type networks. Yet, among the triangular motifs types 6 and 8 are conspicuously absent in the Party Initiation network, consistent with the low level of reciprocity in the networks.

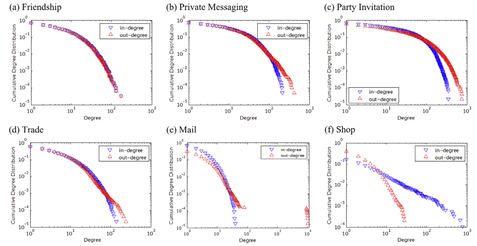



**Figure 4. The in- and out-degree distributions in AION are most dissimilar in the case of the Mail and Shop networks.** In Shop, the highly skewed in-degree distribution is caused by the existence of *aemagnate merchants* In Mail, the outliers in the out-degree nodes specify a special class of high-volume senders such as in-game managers.
doi:10.1371/journal.pone.0033918.g004





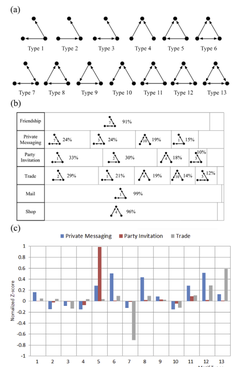



**Figure 5. Network motif analysis of node triplets reveal detailed interactions patterns in directed networks.** (a) The thirteen possible motifs composed of three nodes in a directed network. (b) The fractions of each motif type in each of the six networks. Motifs accounting for fewer than 10% of the motifs are not shown. Friendship, Mail, and Shop each show one dominant motif, consistent with the high or low reciprocity found in the networks. (c) A closer look at the (normalized) Z-score triad census of Private Messaging, Party Invitation, and Trade networks where no dominant motif is evident, we used the Z-score method is employed to determine significantly over- and underrepresented triangular motifs. Overrepresented motifs (with $Z > 0.4$) are indeed closed triangles, consistent with the relatively high clustering tendencies in these networks.
doi:10.1371/journal.pone.0033918.g005

## C. Network Overlap

The results for the network overlaps (Link and Degree Overlaps) for all fifteen possible network pairs are given in Figure 6. Examining the link overlap (Figure 6 (a)), we find the Shop network most interesting: while it shows the highest link overlap Private Messaging (in fact, the highest among any network pair), that with any other network is negligibly small. This is a result of the fact that users often engage in conversations when shopping, most often for inventory checking and price bargaining (as we often do in real life), even though it is not mandatory: one can simply pick up an item to buy and pay the asking price, while the low overlap with the other social-type interactions is the result of

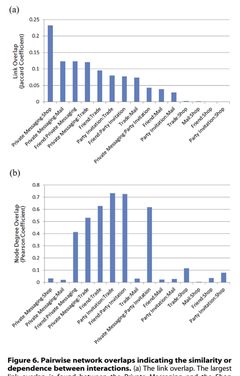



**Figure 6. Pairwise network overlaps indicating the similarity or dependence between interactions.** (a) The link overlap. The largest link overlap is found between the Private Messaging and the Shop networks, reflecting the fact that private messaging (for bargaining) nearly always precedes the sales of items via the Shop interaction. (b) The node overlap quantifying the node degree overlap between different networks. High degree overlaps occur between the four social-type networks, indicating that many gamers make a fair mix of the actions. The low degree overlaps in different pairs indicate the role specialization discussed in the text.
doi:10.1371/journal.pone.0033918.g006

the existence of magnate merchants so that Shop transactions commonly take place between gamers with no particular social or personal relationships. The node degree overlap (Figure 6 (b)) is another way of seeing the connection between interactions: here, for instance, the Party Initiation and the Trade networks show a positive PCC value exceeding 0.7, which can be understood by the fact that a Party activity, being above all the favorite way of engaging in battles or hunting, often concludes with members Trading booties.

## Discussion

In this paper, we studied and compared large-scale multi-relational user interactivity networks representing various types of interactions in AION. Utilizing the framework of network science, we measured and discussed how the the local and the global properties of the networks correlate with the detailed nature and context of the interactions. While so far it is still commonplace in

- Granular & Personal
- Explore Their Own Data
- Compare it with Other Players