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Brainstorming in Solitude and Teams: A Computational Study of the Role of Group Influence

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Abstract

Early studies of brainstorming showed that individuals tend to generate more and better ideas than groups. But recent studies depict a more complex picture, reinforcing the need to better understand the interplay between individual and group ideation. Group influence can be one way to address the complex interplay between ideas in brainstorming. We define group influence as the degree to which individuals are influenced by ideas coming from other team members. This paper presents results from a multi-agent simulation of the role of group influence in brainstorming groups, which support a number of insightful hypotheses to consider.

Introduction

Is it better to generate ideas in solitude or in teams? Creativity research has shown that this distinction is not trivial. Early studies showed that individuals working in privacy tend to generate superior results along three criteria: total number of ideas, number of unique ideas, and quality of ideas [1]. But a more complex picture is portrayed by subsequent studies, reinforcing the need to better understand the interplay between individual and group ideation as well as the importance of facilitation dynamics [2].

The term 'brainstorming' refers to the method of problem solving based on timed sessions where participants are instructed to address a problem by freely generating a large number of ideas irrespective of their apparent value [3]. The aim of brainstorming sessions is to generate as many different alternative solutions to a given problem as possible. Whilst many variants of brainstorming have been proposed, the basic premises are to maximize the number and the originality of ideas, to combine or improve ideas suggested, and to minimize critical evaluation of ideas [4].

Individual brainstorming consists of engaging subjects in idea generation sessions isolated from others. Group or team brainstorming refers to the more typical scenario where individuals interact to generate and evaluate possible solutions to a common problem. Recent studies of idea fluency in brainstorming show that individuals working in solitude outperform non-facilitated teams both in gross and net fluency of ideas; but are considerably outperformed by facilitated teams [2]. As with other factors related to team dynamics, such as diversity and leadership, group influence as a construct and its effects on creative ideation are yet to be fully understood. This is a relevant topic in the still incipient research stream on multi-level approaches to team creativity [5].

The process by which independent individuals consistently surpass group creativity is called 'ideational productivity loss' and appears to have a series of likely cognitive and group-level causes [6]. Cognitive factors that may interfere with ideational productivity include *production blocking*, a product of turn-taking and interruptions, forgetting ideas, and distraction by task-irrelevant processes. A higher cognitive load is also often cited as a source of ideational loss, typically caused by attending to other's ideas.

Group factors that may account for productivity loss include team structure and diversity, awareness of public evaluation, disposition to converge with others' judgments, lower motivation due to shared responsibility, and a tendency to free-ride [7]. The link between group influence and creativity has been addressed only marginally so far. Multi-level approaches are required to understand, for instance, what is the appropriate degree of accessibility to others' ideas when brainstorming in teams in order to ensure that individuals are able to both build upon their own ideas as well as upon the ideas of their teammates.

Teamwork in creativity enables the important process of sharing ideas; however this freedom may have two different effects on creative ideation: one possibility is that teammates generate a wide range of diverging ideas thus obstructing the connection and refinement of coherent 'trains of thought'. The noise generated in this imagined scenario would more likely produce incomplete and incompatible ideas of low quality not to mention dissatisfaction from the participants. A second possibility is that teammates rapidly converge in agreement around one or just a few dominant ideas without exploring other alternatives.

Group influence can be one way to address this interplay between ideas in brainstorming. We define group influence in this paper as the degree to which individuals are influenced by ideas coming from other team members. Here, group influence is a group-level rather than an individual construct. Groups with high influence levels are those where all ideas by all participants are always available to every group member. Groups with low influence levels are those where individuals are only exposed to their own ideas. Between these extremes, group influence indicates the ratio of ideas available to brainstormers.

Following the literature, we use the term *interactive group* to refer to individuals synchronously collaborating in brainstorming and *nominal group* to control groups of the same number of individuals generating ideas alone [2].

In this paper we present results from a multi-agent simulation of the role of group influence in brainstorming groups. Our aim here is to model the interactions between agents engaged in a simple task of divergent reasoning in order to inspect the beneficial and detrimental effects of different team structures in idea generation. In defining this model, we follow the distinctions between ideas, agents and societal factors of the IAS framework for the computational modeling of creativity and innovation as explained below [5]. The rest of this paper is organized as follows: section 2 presents precedent work on the computational modeling of group brainstorming, section 3 introduces our own modeling approach to group influence in brainstorming, section 4 presents the simulations results and section 5 ends the paper with a discussion of the results and their implications in computational creativity research.

Models of Group Brainstorming

This paper presents an approach to the study of creativity using computational social science [7] in order to inspect the mechanisms behind the apparent paradox of ideational productivity loss in brainstorming groups. Computational social science utilizes multi-agent simulations that are useful to explore hypotheses, test assumptions and understand fundamental issues in complex social systems. These systems are also useful to generate predictions for future laboratory experiments or case studies.

Semantic and Social Models

Iyer et al [8] propose a connectionist framework of idea generation in order to inspect experimental data from laboratory studies on ideation and idea priming. In particular they explore the interaction between 'irrelevant primes' and context familiarity; irrelevant cues are defined as sets of ideas of which only a fraction are related to the task at hand, while context familiarity is given by the pre-existing classification of ideas defined in the system.

With this model, the researchers emulate the laboratory results and provide hypotheses as to why even irrelevant primes can increase idea quality and fluency. By manipulating the degree of familiarity between contexts, they show that when irrelevant primes are used between two completely unfamiliar contexts, there is no benefit, whilst irrelevant priming is useful only when partial information about semantic relationships is shared between search contexts. In this vein, the authors suggest future experimental studies on the creative capacity to create 'short-cut linkages' between features, concepts or semantic categories that are typically not related.

In an extension of this work, Paulus et al propose an ongoing approach to model group creativity by vertically integrating neural and social networks [9]. They define agents as simplified versions of the connectionist model described above, and account for individual differences in semantic contexts, idea association, domains, cognitive strategies and responses to cues. Through what they define as a *parameterized interaction protocol* (PIP), their proposed model accounts for turn-taking between agents and, more relevant to our approach, the accessibility of ideas by either the entire group or a selected few. With this model still under development and testing, the authors aim to address a range of research questions, including the efficiency of certain interaction structures and scheduling protocols for group ideation.

Group Influence in a Design Task

From the perspective of computational social science, creative systems are modeled by multiple generators and evaluators of ideas linked in a social system. In such systems, creativity is explained as an emergent outcome, i.e. a global effect that 'grows' from rather simple local interactions [10]. The model presented here is defined using the channels of interactions specified in the *IAS* framework (ideas, agents, society) [10]. Agents (*A*) engage in a simple designing task that constitutes the agent-idea channel (*Ai*) where the resulting designs belong to the set of Ideas (*I*); social structures (*S*) determine the availability of ideas (*Si*); ideas are used by agents (*Ia*) to build design concepts (*Aa*) that are further applied in the design of new ideas (*Ai'*).

In this model, *Ai* is implemented as a shape search process starting from an initial set of polygons and affine transformations, *I* is the set of final shape representations produced by the agents, *S* is the arrangement of agents in groups, *Si* is the experimental variable of group influence, *Ia* is a transmission mechanism of ideas to agents, and *Aa* is modeled as an inference process of design concepts. At the moment, this model is limited to only four of the nine channels of interaction in the *IAS* framework, namely: *Ai, Si, Ia* and *Aa*. In the future, we plan to integrate and examine more *IAS* processes in this model including leadership styles (*As*), compliance to group majority (*Sa*), group agreement to adjust idea influence (*Is*), etc.

A description of the simplified design task implemented in this system can be formulated as: "within a fixed time period, generate as many different shape compositions as possible by manipulating the location, orientation and scale of two triangles". Shape compositions are defined as arrangements of two initial shapes that produce more than two final shapes. New shapes are created by the superposition of existing shapes which lead to the identification of new vertices in the intersections of line segments. This enables the emergence of new shapes as the set of paths {*LM*} from between the start and end points of figures *L* and *M* that lead through each intersection point, traversing each segment no more than once [11]. This shape arithmetic task provides a relative quantitative measure to compare two or more sets of results. A quality criterion is defined for this task as a function of the total number of new shapes created and their maximal number of sides.

The task is used to study brainstorming by implementing a multi-agent system where agents are automated shape generators that search for new solutions and derive design concepts in a fixed time period. Agent behavior in this simplified model of brainstorming consists of the following behaviors: exploration function (random shape drawing and transformation), evaluation function (concept formation from topology relationships of shapes), and exploitation function (shape drawing and transformation by application of learned concepts).

Shape exploration in this program can be considered potentially creative inasmuch as emergent shape semantics "exists only implicitly in the relationships of shapes, and is never explicitly input and is not represented at input time" [12]. The primary shape in this particular system is constrained to triangles, while new nodes based on line segment intersection produce emergent polygons of more than three sides.

A design concept is defined here as a topology relationship between the initial shapes associated to the fitness of the final shape composition. More details are provided below. After a designer agent has generated one or more concepts, it can use them to generate new shapes. Exploitation strategies consist of random variations to existing design concepts. New compositions can then be obtained as a result of applying the modified rule and evaluating whether its outcome yields a new shape composition.

The following pseudo-code shows the algorithm to generate initial shapes and new emergent subshapes in this task (exploration function):

```
for(initialShapes) {
  select three random (x,y) points
  connect all pairs of points with lines
  build a polygon with resulting lines
}
while (!lineIntersection) {
   translate shapes in random(δx,δy) increments
      for(every line i of every polygon) {
         find intersection point(line_i-line_n)
         store all vertex in a set
      }
}
for(all vertex in set) {
  build all subshapes via graph search (dijkstra)
  store new subshape in a set
}
eliminate duplicate subshapes
```

The following pseudo-code shows the algorithm to assign a qualitative measure to shape compositions (first part of evaluation function):

```
for(finalShapes) {
  fitness += (sides of subshape * finalShapes)
}
```

The following pseudo-code shows the algorithm to build design concepts in this task (second part of evaluation function):

```
for(initialShapes) {
   shapeA.insideVertex += (vertex is within boundaries of shapeB)
   shapeA.outsideVertex += (!vertex is within boundaries of shapeB)
   shapeA.inLine += (vertex intersects line of shapeB)
  shapeA.coincidentVertex += (vertex is coincident with vertex of
shapeB
}
   designConcept = { {shapes.insideVertex, shapes.outsideVertex,
shapes.inLine, shapes.coincidentVertex} , fitness}
   store designConcept in a set
```

Figure 1 illustrates six possible compositions created by this generative program. Further details on the complexity of this task are found elsewhere [13]. This two-dimensional shape representation is used to model divergent visual reasoning and is similar to those typically used in brainstorming research [6]. Whilst this design task is fairly straightforward to implement in a computer system, the results are varied enough to capture some of the key properties of design situations such as open-ended problem formulations with many appropriate solutions, and incremental development of solutions.

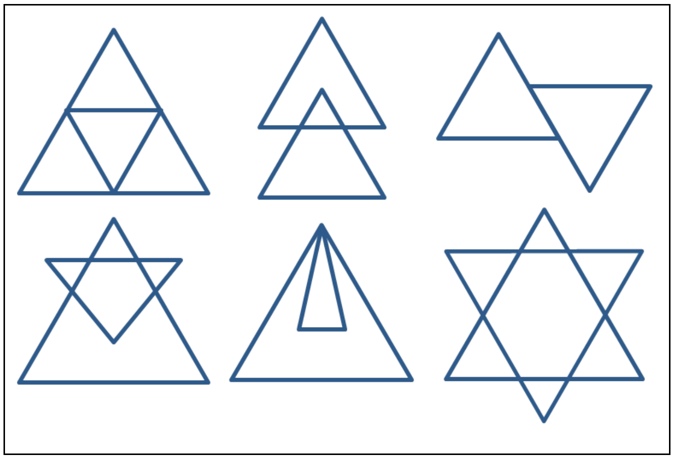


Figure 1 Six random compositions of two overlapping triangles with emergent subshapes ranging from 2 to 27, each subshape from 3 to 12 sides. Subshapes with more sides and compositions with more subshapes are ranked higher.

The exploration and exploitation mechanisms used here are inspired in the classic notions of divergent or 'horizontal' and convergent or 'vertical' thinking processes [3]. During brainstorming sessions, one may assume that exploration enables the discovery of new types of solutions, whilst exploitation allows for the generation of alternatives or new instances. In this system, at initial time a designer agent tends to engage mainly in random behavior (exploration). As a simulation progresses, the agent tends to direct its generative process based on derived concepts (exploitation) as long as this strategy renders new shapes. This is measured by a change in the resulting fitness when generating new shapes using the parameters defined by the design concept. The following pseudo-code shows the algorithm for the exploitation function:

```
for(designerAgents) {
  if (set of concepts == empty) strategy = "exploration"
  else {
    strategy = "exploitation"
    select a random designConcept  from set of concepts
    switch (designConcept) {
      case (insideVertex): initialShapes(insideVertex)
      case (outsideVertex): initialShapes(outsideVertex)
      case (inLine): initialShapes(insideVertex)
      case (coincidentVertex): initialShapes(coincidentVertex)
      }
   if (newFitness != fitness) add designConcept to set
   else strategy = "exploration"
   }
}
```

Group influence γ is defined as a sharing ratio of concepts: in the extreme case where $\gamma = 0$, agents have no access to the concepts generated by other agents; for cases $\gamma > 0$, agents have access to a fraction of the concepts generated by other agents up to $\gamma = 1$, where all agents have access to all concepts generated in the group.

In this paper we present and discuss results of four-member groups where group influence γ is the experimental variable, and both quantity and quality of generated ideas is the dependent variable. The impact of varying the level of group influence in idea fluency is likely to provide a possible explanation of the mechanisms behind the well-documented yet poorly understood phenomenon of 'ideational productivity loss' in group brainstorming.

Results

All results are mean values of 15 cases for every experimental condition. Control random-generator seeds are used in order to compare the effects of the independent variables alone in each case. Outliers are defined as values over 2 standard deviations apart from the mean, and are excluded from the resulting dataset. The statistical significance of these results is below a p-value of 0.05.

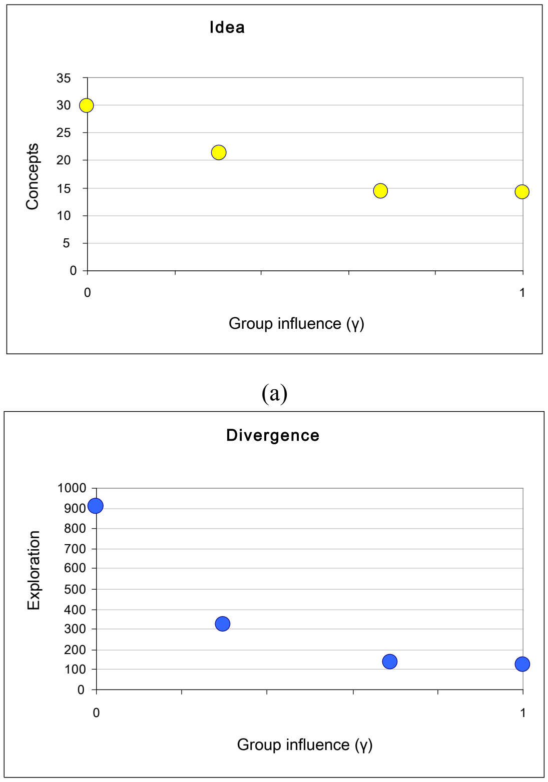
The experimental variable γ is explored in four discrete values: $\gamma = 0$, $\gamma = 0.33$, $\gamma = 0.66$, and $\gamma = 1$. In other words, this experiment ranges from groups where agents have no influence over each other (as in nominal groups), to the type of groups where every agent is equally likely to influence the rest of the group (as in interactive groups).

The tendency regarding the generation of unique concepts or solutions is clear: as the scope of influence of ideas between team members increases, the resulting number of unique concepts decreases. This is consistent with the literature.

Table 1. Results for γ in four steps: no influence, influence between two, three, and with all four team members.

Group γ	**Solutions**	**Explore**	**Exploit**
$\gamma = 0$	299	910	12294
$\gamma = 0.33$	213	322	12557
$\gamma = 0.66$	144	139	12630
$\gamma = 1$	141	126	12638

Similarly, as agents increase their scope of influence within the team, their explorative behavior decreases significantly. The significance of these results is in the shape of this trend. As Figure 2(a) shows, the number of unique concepts rapidly decreases when influence between members of a team is increased above zero. In other words, a minimum amount of influence in a real group causes a sharp fall of production of unique solutions. However, as influence approaches 1, this decrease slows down significantly. This continues to a degree to which having influence over half of team members makes only a marginal difference to having influence over all members.



(a)

(b)

Figure 2. Graph of the effect of group influence on (a) unique concepts and (b) explorative behaviour

A similar shape of change in explorative behavior may explain these effects. As shown in Figure 2(b), nominal groups (where $\gamma = 0$) repeatedly engage in divergent strategies. However, the slightest influence between pairs of participants ($\gamma = 0.33$), causes a sharp decline of explorative strategies. Compared to this, the effects on exploration are only marginal between $\gamma = 0.66$ and $\gamma = 1$, i.e., groups where members are likely to influence half or all of the team, respectively.

Figure 3 plots the correlation between unique solutions and explorative behavior in this system for the γ values inspected. This relationship is termed the 'brainstorming efficiency' of a group and is used as a measure of ideational productivity. The idea is to provide an estimation of unique concepts generated during a brainstorming session against the instances of exploration (i.e., blind or non-directed random changes in this system). The result provides support for an interesting interpretation of group creativity.

In this system, individual agents that work independently ($\gamma = 0$) engage in a very large number of exploration strategies during a session (mean = 910, as shown in Table 1, first row). As a result, these individuals generate a mean 299 unique solutions. When these agents are placed in a group where they can influence a maximum of one participant ($\gamma = 0.33$), their explorative behavior decreases sharply to 322 strategies of exploration. However, these teams still generate quite a large number of original solutions (213). Therefore, the productivity actually increases two-fold between these cases.

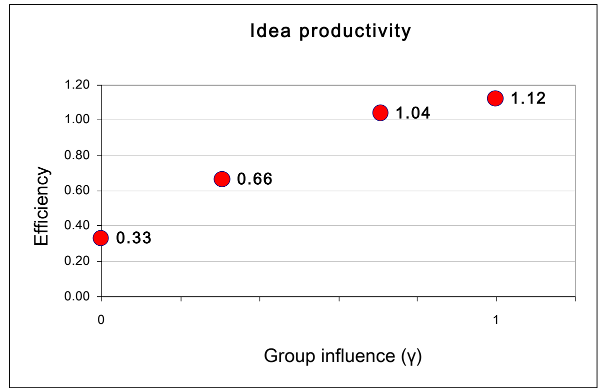


Figure 3. Correlation between unique solutions and explorative behaviour as a measure of idea productivity

As group influence continues to increase, the generation of unique solutions becomes even more efficient in terms of exploration: explorative strategies are required less and less frequently in order to generate original solutions. For instance, when $\gamma = 0.66$ (i.e., group members are able to influence half of the group), the ratio between exploration strategies and original solutions approaches one. And when influence is open between all members of a brainstorming group in this system ($\gamma = 1$), more concepts are generated than instances of explorative behavior during a brainstorming session.

The reasoning behind this effect is that as the scope of influence extends, the likelihood of having an existing concept at hand to exploit at every iteration step increases. As a consequence, the need to generate new concepts decreases in such groups. Team members find it easier to build upon existing concepts when these are generated collectively by the group.

Whilst it is true that interactive groups generate less unique solutions than nominal groups in brainstorming sessions, this experiment suggests that solutions generated by a group may be considered to be significantly 'cheaper' than those built independently by isolated individuals. This may be the case in tasks or domains where generating solutions based in changes to existing concepts is easier than creating entirely novel concepts.

The actual values shown in these Figures are relevant to the task at hand in this system. One may expect that different tasks would yield different numerical results. For instance, in Figure 3 the ratio between exploration and original solutions can be expected to vary as a function of the task's difficulty. Therefore, these results cannot be generalized outside the scope of this computational implementation. Nevertheless, it is significant that in a simple model of group brainstorming like this, small changes in how – otherwise equivalent– designer agents interact, can explain significant and consistent changes in production blocking and idea productivity in teams.

These results further suggest that a medium level of influence could be more productive than no influence or total influence. With a balanced $\gamma = 0.66$, groups in this study generate 50% of the nominal groups' solutions with only 15% of the nominal groups' concepts. There seems to be an optimal trade-off of group hierarchy and creativity ideation where a high number of original ideas is generated with low effort. Thus, generating creative ideas in solitude seems to be extremely inefficient.

Discussion

Is it better to generate ideas in solitude or in teams? Each condition may present certain advantages. Although no definite answer can be expected from this simple model of brainstorming, it does capture interesting observations related to one of the key causes associated to ideational productivity loss, i.e. production blocking in groups. Within its limitations, this model supports a number of insightful hypotheses to consider:

- Transformative creativity may be more appropriate for brainstorming in solitude, whilst combinatorial creativity may be a more suitable objective of teams.
- High hierarchies in brainstorming groups should be avoided since they bring 'the worst of both worlds': less original ideas with high search demands. In such groups, every original idea requires a large number of new concepts learned.
- Likewise, flat hierarchies are unproductive because there are no synergies between explore/exploit processes; the concepts learned are not applied to find new solutions. This is the typical brainstorming session of very creative individuals where many "what if?" questions are asked while most of them are lost and left unaddressed.
- An optimal balance or trade-off can be defined where idea efficiency is high: optimal number of ideas over concepts learned. In such groups not many new concepts are required and they are exploited by everyone to generate solutions.

These results only tell us something about the effect on influence over ideas, it is natural to expect that the complexity of the task will have a major influence, also the degree of agreement or debate in the group, and naturally all cognitive, emotional and other social and individual factors. Nonetheless, our results can be cautiously compared to those from laboratory studies. For instance, a widely-cited study of 4-person groups in the same two assessment conditions shows a productivity loss of around 60% between interactive and nominal groups [14]. In our system the difference is just under 40% in 4-agent groups, and it exceeds 50% in 8-agent groups. The difference between these cases could be due to other factors at work, i.e., the task in that study involves debate on public policy and immigration, which are highly controversial topics that may cause various types of social influences.

On the other hand, another study where the total number of ideas is considered in 4-people groups but in a simpler task, reports a mean difference of 38% between nominal and interactive groups [15]. In this case the brainstorming problem is "what would happen if everyone had an extra thumb on their hand", a kind of open-ended problem of multiple-uses.

The close convergence of our results with this case could reinforce the idea that the nature of the task would determine the scale of the effects on ideational productivity loss.

Nevertheless, the aim of this system is not to replicate a particular task or set of results, but rather to demonstrate the nature and effects of production blocking in teams or interactive groups.

In addition, these findings provide a possible explanation as to why people may enjoy more working in groups than in isolation [16, 17]. Apart from a number of social reasons, in terms of idea generation, our experiments suggest that individuals may be more productive when they operate in groups. Namely, significantly less frequent explorative behavior is required to generate each solution.

If the results of this experiment were able to be generalized, then facilitators of brainstorming sessions should consider the aim of the session in relation to the type of demands imposed over the search of solutions, the degree of transformative or combinatorial creativity required, the social influence of the group (as a sum of paired influences between team members), and the resulting hierarchical interactions between brainstormers.

As depicted in Table 2, brainstorming facilitation should be used to adjust group dynamics to the degree of social influence in a group depending on the desired outcome.

Table 2. Consequences of different group influence structures. A balanced group hierarchy is likely to support combinatorial creativity yielding original ideas with low effort.

Nominal	Low influence	Med influence	High influence
Transformative	Combinatorial	Combinatorial	Combinatorial
More ideas	Less ideas	Less ideas	Few ideas
Least efficient	Efficient	Very efficient	Inefficient

Brainstorming has been treated in general as a 'black box' method of problem solving. People are allocated into teams and they are expected to come up with solutions in a period of time with the general rule that they generate ideas without constraints. The importance of these simple computational experiments is that they show that the results of brainstorming sessions can be qualitatively different between independent individuals and groups, and also between different types of groups. Further modeling will be necessary in order to formulate and evaluate research-based instructions for adequate brainstorming sessions [18]. This paper has suggested that more precise rules and techniques are required to manipulate the settings of group brainstorming according to conditions such as the structure of the group, the strength of group ties, levels of expertise, chains or hierarchies of command, group size, and type of task at hand.

Acknowledgements

This research is supported in part by the National Science Foundation under Grant No. NSF IIS-1002079. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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