1. Introduction

Two philosophies for organizing programming teams have achieved a moderate amount of popularity, if not utilization, in the data processing field. These are the egoless programming team proposed by Weinberg [28] and the chief programmer team proposed by Mills [18] and implemented by Baker [1]. In Weinberg's structure, the decision-making authority is diffused throughout project membership; in Baker's team, it belongs to the chief programmer. Communication exchanges are decentralized in Weinberg's team and centralized in the chief programmer organization. Neither structure is totally
decentralized, democratic, centralized, or autocratic, but both Weinberg and Baker present arguments on why their methods will lead to superior project performance. Baker's project succeeds with a specific, difficult, and highly structured task. Weinberg's recommendations have no specific task in mind.

Research conducted in small group dynamics [7, 23, 27] suggests that a decision to use either team structure is not clear-cut and that there are strong task dependencies associated with each group's performance. The next two sections analyze Weinberg and Baker's organizations. In Section 4, a third, commonly encountered team organization is presented for the purposes of comparison. The fifth section conducts this comparison, recommending which of the three structures should be selected for a given property of a programming task.

2. An Analysis of Weinberg's Team Structure

Weinberg is a promoter of the egoless programming concept. His teams are groups of ten or fewer
Individual programmers have varying skill levels and areas of expertise.

Fig. 1. Egoless Team Structure. Authority is dispersed and communication linkages decentralized.

Bavelas [3] and Leavitt [14], in their experiments on centralized and decentralized group problem-solving behavior, found that decentralized groups take more time and generate twice as many communications as centralized groups. This suggests that a Weinberg group would function well in long-term continuing projects without time constraints (such as program maintenance). It would not, however, adequately perform a rush programming project.

A second weakness of Weinberg’s proposal is the risky shift phenomena [5]. Groups engage in riskier behavior than individuals, both because of the dispersion of failure and the high value associated with risk taking in Western culture. In the case of a group programming team, decisions to attempt riskier solutions to a software problem or to establish high risk deadlines would be more easily made. In a software project with a tight deadline or a crucial customer, a group decision might cause the project to fail.

The democratic team structure works best when the problem is difficult. When the problem is simple, performance is better in an autocratic highly structured group [12]. Ironically, democratic groups attempt to become more autocratic as task difficulty increases. In the decentralized group, the additional communication which aided in solving the difficult problem is superfluous; it interferes with the simple problem solution. Tasks such as report generation and payroll programming fall into the category of simple tasks—for these, a Weinberg group is least efficient.

The decentralized group is lauded for its open communication channels. They allow the dissemination of programming information to all participants via informal channels. By virtue of code exchanges and open communication, Weinberg concludes that the product will be superior. March and Simon [16] point out that hierarchical structures are built to limit the flow of information, because of the human mind’s limited processing capabilities. In the decentralized groups, as investigated by Bavelas, although twice as many communications were exchanged as in centralized groups, the groups often failed to finish their task. Similarly, individuals within a nonstructured programming group may be unable to organize project information effectively and many suffer from information overload.

Despite the pressure to conform and an apparent lack of information organization, decentralized groups exhibit greater conformity than centralized groups [11]; they enforce a uniformity of behavior and punish deviations from the norm [20]. This is good if it results in quality documentation and coding practices, but it may hurt experimental software development or the production of novel ideas.

In summary, Weinberg’s decen-
Centralized democratic group does not perform well in tasks with time constraints, simple solutions, large information exchange requirements, or unusual approaches. A difficult task of considerable duration which demands personal interaction with the customer is optimal for a Weinberg team.

3. An Analysis of Baker’s Team Structure

Baker describes the use of a highly structured programming team to develop a complex on-line information retrieval system for the New York Times Data Bank; the team is a three-person unit. It consists of a chief programmer, who manages a senior level programmer and a program librarian. Additional programmers and analysts are added to the team on a temporary basis to meet specific project needs. Figure 2(a) illustrates the structure of the chief programmer team; the communication channels are shown in Figure 2(b).

The chief programmer manages all technical aspects of the project, reporting horizontally to a project manager who performs the administrative work. Program design and assignment are initiated at the top level of the team. Communication occurs through a programming library system, which contains up-to-date information on all code developed. The program librarian maintains the library and performs clerical support for the project. Rigid program standards are upheld by the chief programmer.

The Baker team is a centralized autocratic structure in which problem solutions and goal decisions are made at the top level. The task which the team undertakes is well-defined, but large and complex. Definite time constraints exist. Baker concludes that this compact highly structured team led to the successful completion of the project and that it has general applicability.

Several weaknesses exist in Baker's argument. Shaw [21] finds that a centralized communication network is more vulnerable to saturation at the top level. Information from all lower modes in this structure flows upward to the parent mode. Baker’s team was intentionally small and worked with a highly structured system for managing project information; both these factors were critical to the success of the project. A third, equally important factor was the team leader's ability to handle project communication. This ability is closely related to the leader's software expertise. A less experienced leader or a more complex problem might have changed the project's success, even with staffing constraints and information management. Yourdon [29] points out that the effective chief programmer is a rare individual and indicates that most so-called chief programmer teams are headed by someone who is unlikely to adequately handle the communication complexity.

Centralized groups exhibit low morale [3]; this, in turn, leads to dissatisfaction and poor group cohesiveness. Members of highly cohesive groups communicate with each other to a greater extent than members of groups with low cohesion [15]. With a clearly defined problem that is split into distinct modules, this lack of communication will have little impact, but an ill-defined problem with many interfaces would suffer in a chief programmer team environment. The two software modules (the interface systems) on this project which might have served as indicators of this communication condition are, as a matter of fact, developed as a joint effort between the chief programmer and another team member.

Communication in a status hierarchy tends to be directed upward; its content is more positive than that of any communication directed downward [27]. In a tricky, difficult programming task, this favorable one-way flow of communication denies the group leader access to a better solution or, at least, an indication of problems in the current solution. Decentralized groups generate more and better solutions to problems than individuals working alone [25]—such as a chief programmer. The major basis for the success

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Fig. 2. Chief Programmer Team Structure. Authority is vested in the chief programmer and communication is centralized to this individual.
of the New York Times Data Bank project was the team's ability to meet the delivery date. A centralized structure completes tasks more quickly than any decentralized form of control [14], but perhaps a more creative solution might have resulted from a different approach. Proponents of good software management stress concern for the software life cycle [8, 9, 13]. This implies that consideration be given not only to project completion schedules but to the software's usability, cost to the customer, and modifiability.

In summary, communication exists to a much lesser degree in centralized groups and is directed toward the manager. Both difficult tasks requiring multiple inputs for solution and unstructured tasks requiring substantial cooperation fare poorly in this kind of communication environment. Group morale and, thus, goal motivation are low in such a hierarchical structure. A simple, well-structured programming task with rigid completion deadlines and little individual interface with the client is perfect for the chief programmer team.

4. An Analysis of a Controlled Decentralized Team Structure

In practice, programming team structures vary considerably. Most take on some form of organization that draws from both Weinberg's egoless team and Baker's chief programmer team. A third, frequently used organization which we will call the controlled decentralized (CD) team is described in this section.

The controlled decentralized team has a project leader who governs a group of senior programmers. Each senior programmer, in turn, manages a group of junior programmers. Figure 3(a) illustrates the organization of this group; Figure 3(b) indicates the flow of communication that takes place in this type of group structure.

Metzger [17] describes this organization as a reasonable management approach. He makes two recommendations: First, he suggests that intermediate levels of management are preferable to requiring all senior programmers to report to the project leader and, second, he recommends that the programming groups be partitioned not according to code module assigned, but in terms of the type of role played in the project, e.g., test, maintenance, etc. Shneiderman [24] lists this structure as the most probable type of project organization. Like Yourdon [29], he suggests that the individual subgroups in the project participate in structured walkthroughs and code exchanges in the manner of Weinberg's egoless teams.

The CD team possesses control over the goal selection and decision-making aspects of the Baker team and the decentralized communication aspects of the Weinberg team. Setting project goals and dividing work among the groups are the tasks of the project leader. More detailed control over the project's functions is assigned to the senior programmers. Within each programming subgroup, the organization is decentralized.

4.2. Communications of the ACM

Fig. 3. Controlled Decentralized Team Structure. Authority is vested in the project leader and senior programmers, but communication at each level of the management hierarchy is decentralized.
Programming tasks that are not easily subdivided suffer in a CD team. Note in Figure 3(b) that communication between groups occurs at the senior programmer level. Projects requiring micro-decision communication about code interfaces cannot expect this communication to be conveyed effectively through a liaison person functioning at a macro level in the project.

In summary, the controlled decentralized team will work best for large projects which are reasonably straightforward and short-lived. Such teams can be expected to produce highly reliable code but not necessarily on time or in a friendly manner. They are ill-suited for long-term research-like projects.

Team Structure and Programming Task Relationships

This section describes seven salient properties of programming tasks and compares the performance of each team structure discussed in relationship to these task properties. The relevant properties are:

(1) Difficulty. The program required to solve the problem can be complex, consisting of many decision points and data interfaces, or it may be a simple decision tree. Distributed processing systems and projects with severe core or rapid response time constraints fall into the difficult category. Much of the scientific programming would come under the simple category heading.

(2) Size. Programs may range from ten to hundreds of thousands of lines of code for any given project.

(3) Duration. The lifetime of the programming team varies. Maintenance teams have a long lifetime; one-shot project teams have a short lifetime.

(4) Modularity. If a task can be completely compartmentalized into subtasks, it is highly modular. Most programming problems can be split into subtasks, but the amount of communication required between the subtasks determines their modularity rating. A tape system for payroll reports is a highly modular task.

A data management system for the same purpose has a low degree of modularity.

(5) Reliability. Some tasks such as patient monitoring systems have severe failure penalties, while other tasks, such as natural language processing experiments, need not be as reliable, although working programs are always desirable. The reliability measure depends on the social, financial, and psychological requirements of the task.

(6) Time. How much time is required for task completion? Is the time adequate or is there time pressure? The penalty for not meeting a deadline strongly affects this measure.

(7) Sociability. Some programming tasks require considerable communication with the user or with other technical personnel, such as engineers or mathematicians, while other tasks involve interaction with the team alone. Computer center consulting groups that develop user aids have higher sociability requirements than groups programming their own set of software tools.

Throughout this paper, the labels egoless programming team and chief programmer team have prevailed. For the purposes of comparison, these terms have been changed to names reflecting the decision-making authority and communication structure of the teams. The three teams are:

1. Democratic Decentralized (DD). This group is like Weinberg's proposed team; it has no leaders, but appoints task coordinators for short durations. Decisions on problem solutions and goal direction are made by group consensus. Communication among members is horizontal.

2. Controlled Decentralized (CD). The CD group has a leader who coordinates tasks. Secondary management positions exist below that of the leader. Problem solving remains a group activity but partitioning the problem among groups is a task of the leader. Communication is decentralized in the subgroups and centralized along the control hierarchy.
problem solving and goal directions

This group is like Baker's team. Both

drawn from experimental research
tors governing program tasks can be
of these team structures with the fac-
path of control.

are generated by the team leader.

was completed.

time in which the code generation
quality of generated code and the
performance quality, team structures
are assumed to be evaluated on the
ple problems are best performed by
nder the category
ple solutions. Directive leadership is best
l action and morale than CD or CC

Table I lists recommended group
structures for each task variable. Un-
der the category task difficulty, sim-
ple problems are best performed by
entralized structure which com-
letes tasks faster. Decentralization
works best for difficult problems.
Groups are found to generate more
and better solutions than individuals.
Unfortunately, the CD team is cen-
ralized precisely where the problem
is difficult. The DD team is the best
solution for difficult problems. For
impler programming tasks, a CC or
CD structure is recommended.

As programming tasks increase
in size, the amount of cooperation
required among group members in-
creases. Group performance is neg-
atively correlated with the coopera-
tion requirements of a task. As tasks
become very large, the DD group is
no longer viable because of its co-
operation requirements. CC and CD
groups can be effectively regrouped
into smaller structures to handle the
task. When the task size requires a
smaller number of programmers, the

DD group performs better because
of its high level of communication.
For very small tasks, the CC group is
best because it does not require the
additional communication of demo-
cratic groups; but then, a group is
unnecessary. An individual will do.

The duration of the task interacts
with group morale. Short tasks may
not require high group morale, whereas
long tasks will suffer from
high personnel turnover if morale is
low. DD groups have high morale
and high job satisfaction. This
should be the preferred group struc-
ture for ongoing tasks. The CC and
CD groups are effective for short-
term tasks.

If task modularity is low, the DD
group performs best because of its
higher volume of communication.
Cooperative (read DD) groups have
higher orderliness scores than com-
petitive (read CC) groups [10]. This
orderliness is essential for main-
taining the interfaces of a low modularity
task. Nondirective leadership has
been found to be most effective when
a task has a high multiplicity of sol-
lutions. Directive leadership is best
for tasks with low multiplicity solu-
tion choices [22]. A DD group can
be characterized as having nondirec-
tive leadership, CC and CD groups
as having directive leadership. High
modularity tasks have a low multi-
ploy of solutions, and thus the CD
and CC groups can be expected to
exhibit the best performance given
such tasks.

CC and CD groups perform well
when confronted with high reliabil-
ity requirement problems. Decen-
tralized groups have been found to
make less errors and produce better
solutions to problems. A CC group
is more error-prone and probably
should never be used for projects in
which relatively simple errors can
result in disaster.

A decentralized group takes
longer to complete a problem than a
centralized group. If tasks have se-
vere time constraints, a CC team is
best. When time is not crucial, the
low motivation of CC groups can
interfere with task completion.
Therefore, the more democratic
groups are preferred, with the DD
structure being the best choice.

If a task requires high sociability,
the DD team structure is best.
Groups learn faster than individuals
(such as the team leaders of CC
groups). Therefore, a DD group
would understand a user's interface
problem in a shorter period of time.
DD groups are higher in social inter-
action and morale than CD or CC
groups. These traits will enhance
their social relationships with the
task contacts.

6. Conclusion

Many programming task features
interact with each other, e.g., a large
project is often a difficult one. Group
structures that are effective for one
aspect of a task may be totally wrong
for another. In selecting a team struc-
ture, it is important to use a decision-
making algorithm to prioritize,
weight, or combine the crucial task
variables.

Little experimental work on pro-
gramming team and task interaction
has been carried out. Basili and Rei-
ter [2] found relationships between
the size of a programming group and
several software metrics. They also

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<th>Group Structures</th>
<th>Difficulty</th>
<th>Size</th>
<th>Duration</th>
<th>Modularity</th>
<th>Reliability</th>
<th>Time Required</th>
<th>Sociability</th>
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<td>High</td>
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<td>Controlled Decentralized</td>
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<tr>
<td>Controlled Centralized</td>
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Communications of the ACM
found cost differential behavior arising from the software development approach taken, with structured techniques being notably cheaper. Only one programming task was performed by the experimental groups. Weinberg's suggestions on group organization are anecdotal and Baker's conclusions are confounded by the team personnel and the programming methods selected.

Most of the research on group problem-solving behavior was conducted in a laboratory setting with students and tasks of short duration. A problem exists in trying to apply these conclusions to the external work environment. In particular, programming tasks generally involve an entirely different time span than laboratory experiments. Becker [4] scathingly criticizes these "cage" experiments. Rogers [19] suggests substituting network analysis field work to understand the effects of group structures.

None of these task/structure recommendations have been tested in a software development environment. Despite all these shortcomings, the application of a body of research on group dynamics to the organization of personnel on a programming project is a step forward from the hit-and-miss guessing that is the current state of the art.

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