COMPUTATIONAL ASPECTS OF THE NONLINEAR NORMAL MODE INITIALIZATION OF THE GLAS 4TH ORDER GCM

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1. INTRODUCTION

Using the normal modes of the GLAS 4th Order Model, a Machenhauer nonlinear normal mode initialization (NLNMI) was carried out for the external vertical mode using the GLAS 4th Order shallow water equations model for an equivalent depth corresponding to that associated with the external vertical mode.

A simple procedure was devised which was directed at identifying computational modes by following the rate of increase of BAL_m, the partial (with respect to the zonal wavenumber m) sum of squares of the time change of the normal mode coefficients (for fixed vertical mode index) varying over the latitude index ℓ of symmetric or antisymmetric gravity waves.

A working algorithm is presented which speeds up the convergence of the iterative Machenahuer NLNMI. A 24 h integration using the NLNMI state was carried out using both Matsuno and leap-frog time-integration schemes; these runs were then compared to a 24 h integration starting from a non-initialized state. The maximal impact of the nonlinear normal mode initialization was found to occur 6-10 hours after the initial time.

2. A MODIFIED NLNMI INCLUDING "COMPUTATIONAL-MODES" FILTERING

Our algorithm for NLNMI consisted of:

a) A linear normal mode initialization

b) A first nonlinear normal mode initialization where suspected computational modes were identified by the rate of increase of BAL_m

$$c = c(k,m,\ell,0)$$

$$BAL_m = \sum_{m'} \sum_{\ell \varepsilon G}^{m} \frac{\partial c}{\partial t} \frac{\partial c}{\partial t}^{*} = \sum_{m'}^{m} \sum_{\ell \varepsilon G} [\delta_t\, c(k,m',\ell,0)]\, [\delta_t c(k,m',\ell,0)]^{*}$$

between subsequent latitude indices ℓ of the symmetric or antisymmetric gravity waves for fixed vertical mode k (k=1, exterior vertical mode). The gravity modes with latitudinal indices ℓ $(14 \leq \ell \leq 44)$ which had a relative increase in BAL_m over a prescribed threshold were identified as "computational modes" and the coefficients of these modes were filtered out by zeroing (linear initialization) instead of using these "computational" coefficients in a full NLNMI.

c) Subsequently a full Machenhauer nonlinear iteration including all indices ℓ was carried out.

The rationale behind this procedure is that the balance, which is the sum of squares of the time change of the coefficients, is affected by the nonlinear terms introduced by the change in the coefficients over the short forecast. The difference $[c(k,\ell,m,\Delta t)]\mu - [c(k,\ell,m,0]\mu$ should be greater for the latitude indices ℓ where computational modes occur - as they are out of balance with the eigenfrequencies (ν') employed in the Machenhauer iterative nonlinear correction. In Figs. 1 and 2 we present the evolution of BAL_m for m = 5 and m = 1 for ℓ = 14 to 44 for the first Machenhauer iteration and the identification of the suspected "computational modes." Other methods for identifying computational modes can be found in F. Baer and P. J. Sheu (1982) and by B. B. Katz (1982).

The present method identifies only those computational modes which affect the convergence of the NLNMI and it filters them out via a linear normal mode initialization.

3. INSENSITIVITY OF THE NLNMI TO EXCLUSION OF THE UPPER THIRD OF THE ZONAL WAVE NUMBERS M (26-37) FROM THE NONLINEAR BALANCE

Following a suggestion of Dr. E. Kalnay (private discussion) we modified the nonlinear normal mode initialization procedure so that the high zonal wavenumbers from m = 26 to m = 37 were only linearly normal mode initialized. We then compared the behavior of the modified process with that of the full NLNMI. The effect on the balance (BAL_m) (see Fig. 4) as well as on the subsequent integration was negligible. This result can be explained by the fact that there are fewer physical modes in the high-wave number range (see also Baer and Sheu, 1983).

4. IMPACT OF THE NLNMI ON SHORT-RANGE FORECASTS (24 H)

A 24 h forecast starting from a nonlinearly initialized state was made using the GLAS 4th Order shallow water equations model using either a leap-frog or a Matsuno time-differencing scheme. The results of those forecasts were compared to the results with 24 h integrations starting from a non-initialized state.

In Fig. 5 we plot the time variation of the height field at a grid point for a non-initialized integration and an integration initialized with two nonlinear Machenhauer iterations; both integrations used a Matsuno time-differencing scheme. Fig. 6 differs from Fig. 5 in that a leap-frog time scheme was used.

5. TIME OF MAJOR IMPACT ON SHORT-RANGE FORECASTS

By following the hourly evolution of the height field for a short-range forecast (24 h) with both nonlinear normal mode initialization and a run with no initialization, we observe a major impact for periods of 6-10 hours (see

Figs. 7-10) for both time-differencing schemes. In the case of a leap-frog time-differencing scheme the impact is still visible after 24 h, whereas for a Matsuno time integration scheme the impact of the NLNMI nearly vanished after 24 hours of integration.

6. CONCLUSIONS

A nonlinear normal mode initialization was successfully applied to the exterior vertical mode of the GLAS 4th Order Model. A new algorithm was developed permitting the identification and subsequent filtering out of 'suspect' computational modes which affect the convergence of the Machenhauer iterative procedure.

By looking at the latitudinal eigenstructures of u, v and ϕ we certified that our procedure identifies computational gravity modes. It is however not exhaustive, as it identifies only the computational modes which affect most significantly the convergence of the Machenhauer iteration. The Machenhauer NLNMI was found to be insensitive to the deletion of high zonal wavenumbers (#26-#37) from the nonlinear balancing process. These zonal waves are only linearly initialized, which results in increased computational efficiency.

24h integrations using both non-dissipative (leap-frog) and dissipative (Matsuno) explicit time-integration schemes were carried out with both nonlinearly initialized and non-initialized data sets. The time of maximum impact of the nonlinear normal mode initialization was located between 6-10 hours. We also found that for the Matsuno scheme the results after 24h are nearly identical for both the non-initialized and the NLNMI states, while for the leap-frog scheme the impact of the nonlinear initialization was still evident after 24h.

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Bloom, S., 1982: Normal modes of the GLAS 4th Order Model. NASA Tech. Memo. 84983, 99-103.

Katz, B. B., 1982: Classification of normal modes of the primitive equations of atmospheric motion. MSc Thesis, Dept. of Meteorology, University of Maryland, College Park, MD, 115 pp.

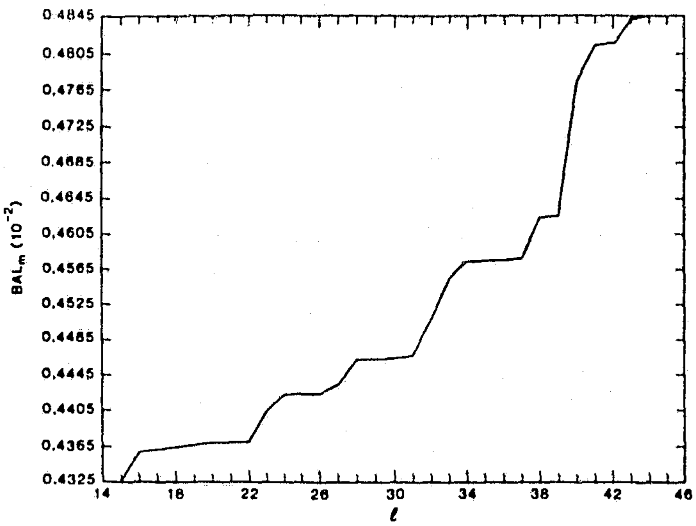

Fig. 1. Evolution of BAL_m for fixed vertical mode $k = 1$ and given zonal wave number $m = 5$, for latitude indices $\ell = 14$ to $\ell = 44$ for symmetric gravity modes.

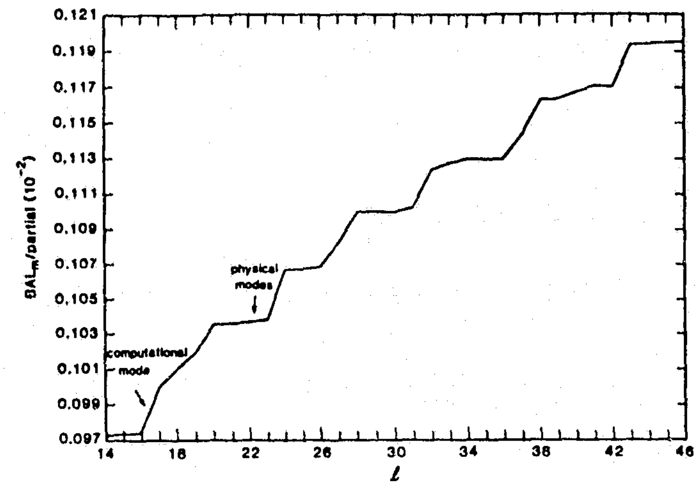

Fig. 2. Evolution of BAL_m for fixed vertical model $k = 1$ and given zonal wave number $m = 1$, for latitude indices $\ell = 14$ to $\ell = 46$ for symmetric gravity modes.

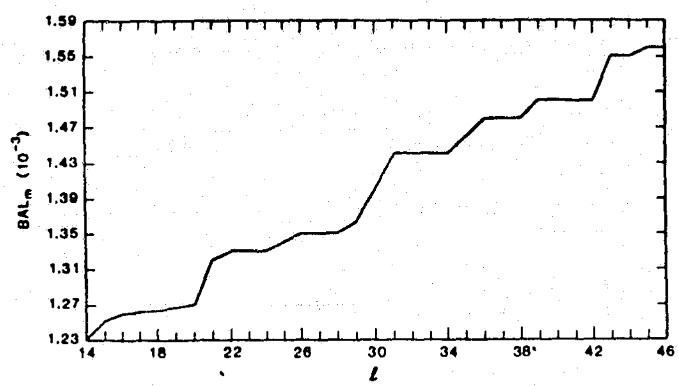

Fig. 3. Evolution of BAL_m for fixed vertical model $k = 1$ and given zonal wave number $m = 1$, for latitude indices $\ell = 14$ to $\ell = 46$, for antisymmetric gravity modes.

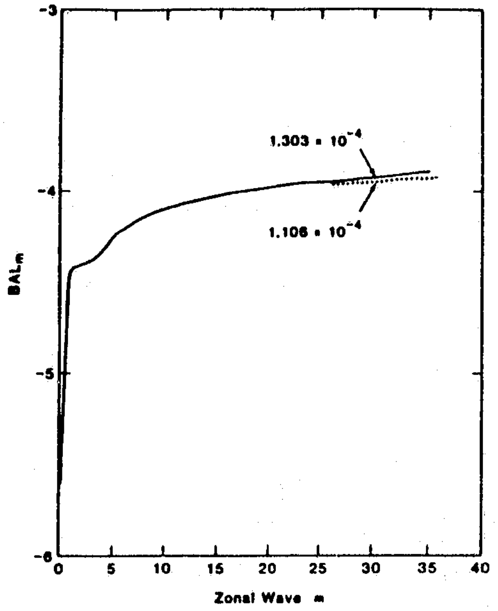

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Fig. 4. Evolution of BAL_m as a function of the zonal wave numbers with full nonlinear Machenhauer iteration for all zonal wave numbers (solid line) and with linear normal model initialization for zonal wave numbers 26-37.

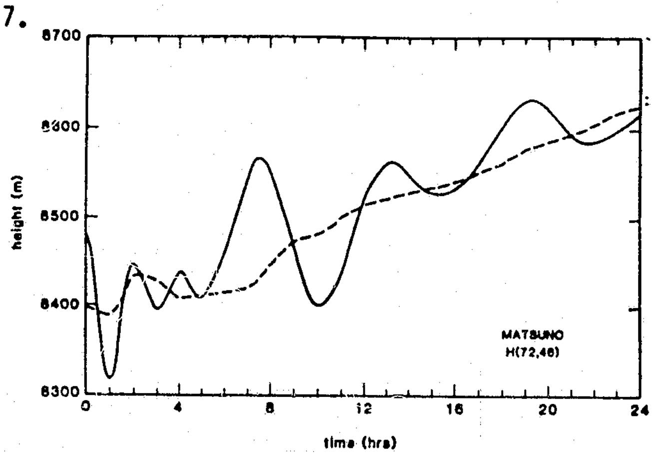


Fig. 5. Time variation of the height field for 24 h at grid point (72, 46) after 2 nonlinear Machenhauer iterations (dotted line) and without initialization (solid line) using Matsuno time differencing scheme.

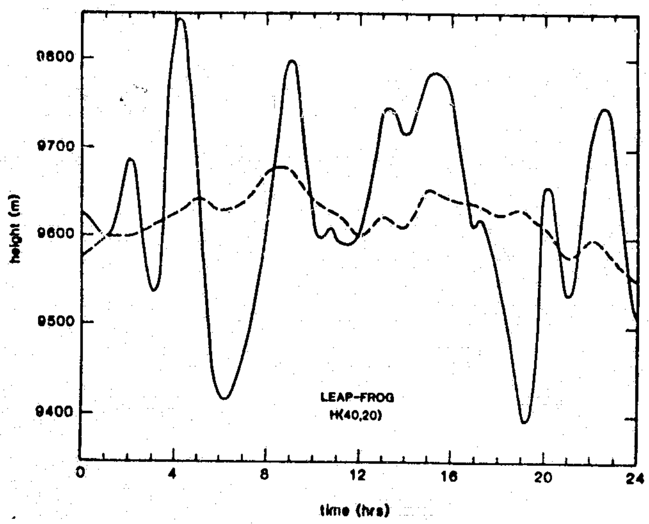


Fig. 6. Time variation of the height field for 24 h at grid point (40, 20) after 2 nonlinear Machenhauer iterations (dotted) and with no initialization (solid line) using a leap-frog time differencing scheme.

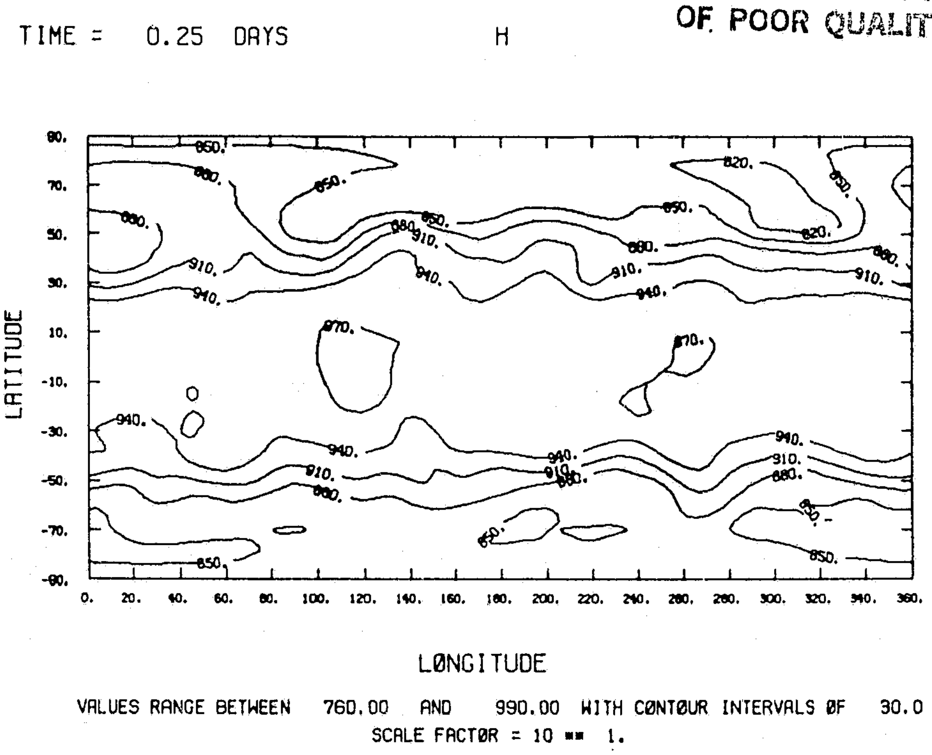


Fig. 7. The height field after 6 hours (0.25 days) starting from nonlinear normal model initialized conditions (values between 7600 m to 9900 m with 300 m contour intervals) (and intergration) with leap-frog scheme.

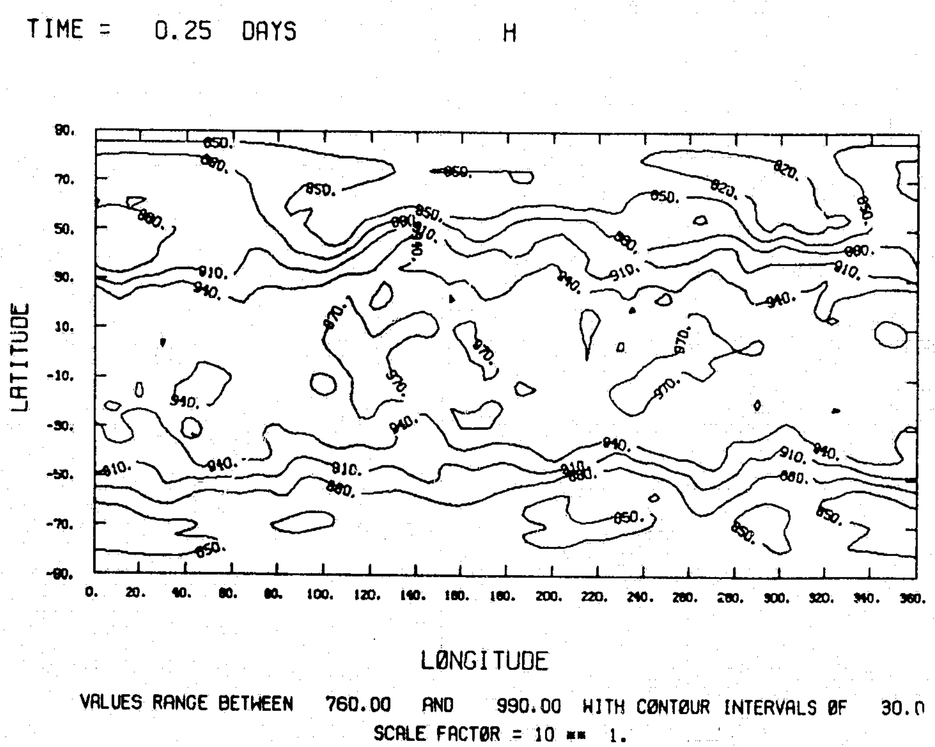
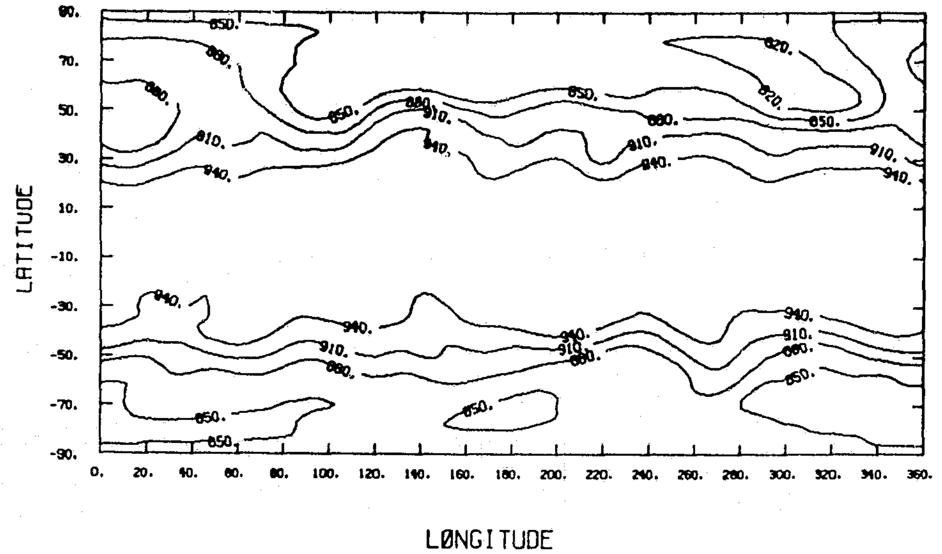


Fig. 8. The height field after 6 hours starting from non initialized conditions and integrated with leap-frog scheme.

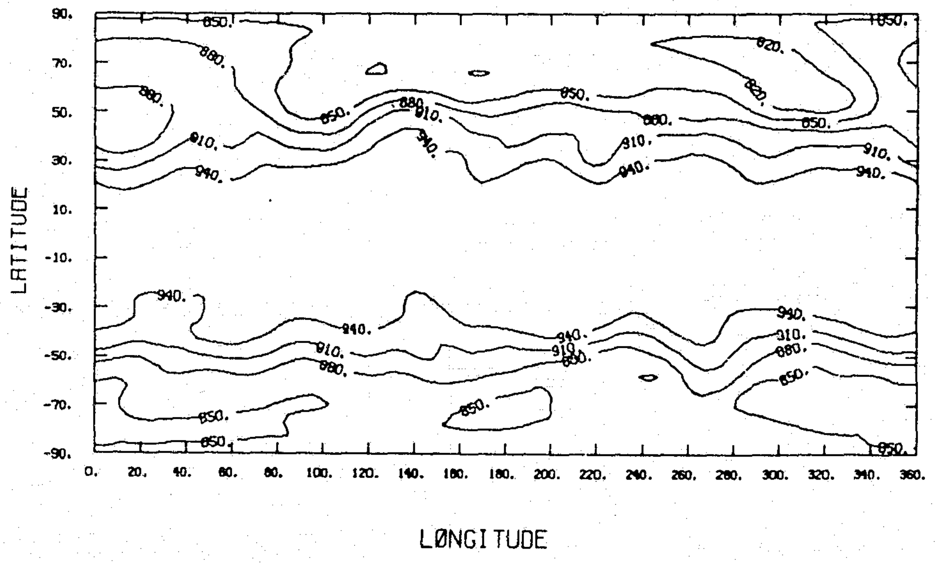
TIME = 0.33 DAYS



VALUES RANGE BETWEEN 760.00 AND 990.00 WITH CØNTØUR INTERVALS ØF 30.0
SCALE FACTØR = 10 ** 1.

Fig. 9. The height field after 8 hours of integration using the Matsuno time scheme starting from nonlinearly normal model initialized conditions.

TIME = 0.33 DAYS H



VALUES RANGE BETWEEN 760.00 AND 990.00 WITH CØNTØUR INTERVALS ØF 30.0
SCALE FACTØR = 10 ** 1.

Fig. 10. The height field after 8 hours of integration using the Matsuno time scheme starting from non initialized conditions.

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A USER FRIENDLY OPERATING SYSTEM FOR THE GLAS 4TH ORDER FORECAST-ANALYSIS SYSTEM

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1. INTRODUCTION

With the acquisition of the CYBER 205 computer in the summer of 1982, the volume (and complexity) of numerical experimentation which could be done in a given time by the Global Modeling and Simulation Branch increased by an order of magnitude. Experiments, which until then had taken weeks, could be done in a matter of days. It soon became apparent that a major revision would be needed in the way experiments were set-up, controlled during execution and examined when finished. An operating system ideally suited to our needs would have a number of characteristics:

- o The software defining the entire system would be maintained in a form which guarantees the reproducibility and quality of the experimental results consistent with high scientific standards.
- o The individual system components (forecast models, objective analysis programs, post-processing programs, job control procedures, etc.) would be easy to modify, so that the alterations needed to define the experiments could be done in a straightforward manner.
- o The possibility of stopping and restarting experiments would have to be part of the system. The production of archival history tapes containing the experimental results should occur in a clean, almost automatic fashion independent of the way in which the experimental computations are scheduled.
- o Preliminary results from each experiment should be made available as soon as possible. The large investment in computational resources needed by these experiments requires that quality checks of the results be made periodically as the experiments progress.

The next section describes the GLAS 4th Order Forecast-Analysis System in terms of its operating system requirements. Section 3 contains a description of the operating system structure and components.

2. THE GLAS FORECAST-ANALYSIS SYSTEM

For research purposes, the Modeling and Simulation Branch has developed a complete forecast-analysis cycle similar to those used at large forecast centers. Although the GLAS system does not have to contend with the severe constraints imposed by having to produce actual forecasts in real time, it must provide for a degree of flexibility for research purposes which is usually not encountered at an operational forecast center. Fig. 1 shows the main components of the forecast-analysis cycle in schematic fashion. Some parts of the cycle, most importantly the GLAS retrievals program, have not yet been fully incorporated into the operating system. However, the operating system is designed to support