Figure 2 **What does attention select as ‘figure’ when two objects have almost identical characteristics? To address this question, Blaser *et al.*[1] superimposed two objects, each with three attributes — orientation, stripe width, and degree of colour saturation. In the experiment, all attributes changed rapidly and continuously over time. In the snapshot shown here, object 1 has narrow stripes that are pink on black and orientated at +45°, whereas object 2 has broad stripes that are red on black and orientated at −45°. The objects were superimposed (3) and observers were asked to maintain attention on one of the objects as the attributes changed. Even after several seconds, observers were able to state which object in the changed display had descended from the initial object. Further results suggest that attention may select all three attributes of one object as ‘figure’, but not a single attribute or a mixture of attributes from both objects.**

To answer this question, Blaser *et al.* used a modified display of two mutable objects and asked observers to monitor either one or two attributes of the tracked object. During the tracking period, all attributes of both objects showed simultaneous, discontinuous jumps, which observers had to report. Observers were able to monitor any two attributes of the same object about as well as they monitored either attribute alone. The implication is that all attributes of the tracked object are perceived as ‘figure’. (If only task-relevant attributes were perceived as figure, performance would be expected to deteriorate when more attributes are monitored.) In a control experiment, observers were asked to monitor one attribute from each object. Here, performance was far worse, showing the difficulty of tracking both objects at once.

In short, attention seems to select all the attributes of one object — even those not immediately relevant to the task in hand — as ‘figure’. But it does not seem able to select one attribute of one object, or a mixture of attributes from both objects. This means that attention selects not individual attributes or locations, but rather visual objects as a whole (that is, a set of locations and attributes linked by Gestalt rules). This result is all the more striking because — unlike in some earlier studies — the deck was not stacked in favour of whole-object selection. It would clearly have been advantageous to select a single attribute or a mixture of attributes from each object had it been possible.

How might objects be selected in the visual cortex? And does the apparent restriction to selecting objects — rather than arbitrary sets of attributes — reflect the limitations of neuronal hardware? A conceptually simple scenario is that attention enhances the representation of one object’s attributes while attenuating those of the other. But how can attention single out the attributes of just one object? Attributes of the other are encoded in closely overlapping neuronal populations, and the anatomy of the visual cortex seems to support only relatively coarse and unspecific attentional feedback.

Perhaps one (task-relevant) attribute is selected at first, with feedback spreading to other (non-task-relevant) attributes of the same object through the neural equivalent of Gestalt rules. Alternatively, it is possible that the initial selection is based on the location. Although superimposed, the two objects would have been large enough to allow attention initially to select a small part of one object, and then spread to other parts, again through Gestalt rules. To see this point, bear in mind that the objects stimulated, in visual cortical area V1 alone, neurons in a cortical region of some 100 mm^2 and several dozens of neuronal ‘hypercolumns’.

It remains to be seen exactly how attention can distinguish between objects represented by populations of neurons that are so intimately entwined. But at the very least, the striking capabilities of visual attention revealed by Blaser *et al.*[1] give us new reasons to think hard about how objects are represented in the visual cortex. ■

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1. Blaser, E., Pylyshyn, Z. W. & Holcombe, A. O. *Nature* **408,** 196–199 (2000).
2. Roelfsema, P. R. *et al. Nature* **395,** 376–381 (1998).
3. O’Craven, E. M. *et al. Nature* **401,** 584–587 (1999).
4. Kapadia, M. K. *et al. J. Neurophysiol.* **84,** 2048–2062 (2000).
5. Olshausen, B. A. *et al. J. Comp. Neurosci.* **2,** 45–62 (1995).
6. Deneve, S. *et al. Nature Neurosci.* **2,** 740–745 (1999).
7. Yeshurun, Y. & Carrasco, M. *Nature* **396,** 72–75 (1998).
8. Lee, D. K. *et al. Nature Neurosci.* **2,** 375–381 (1999).
9. Pylyshyn, Z. W. & Storm, R. W. *Spatial Vis.* **3,** 179–197 (1988).
10. Cavanagh, P. *Science* **11,** 1563–1565 (1992).

Global change

That sinking feeling

Jorge Sarmiento

The land and sea soak up much of the carbon dioxide emitted into the atmosphere. But one set of simulations suggests that global warming could greatly impair this ability.

Burning of fossil fuels and changes in land use — mainly deforestation — are resulting in more CO_2 in the atmosphere and, it seems, global warming. Much of that extra CO_2 is absorbed in ‘sinks’ on land and in the oceans. But what effect will future warming have on these sinks? In their paper on page 184 of this issue[1], Cox *et al.* find that in the long run they absorb carbon much less effectively. According to the authors’ calculations, the result is 2.5 °C greater global warming over land by the year 2100 than the 5.5 °C predicted if the climate–carbon-cycle connection is not taken into account.

At the moment, the annual increase of CO_2 in the atmosphere is less than half of the estimated emissions[2]. The rest is absorbed by the terrestrial and ocean sinks for carbon. So climate projections have to consider not only future emissions but how those sinks will react[3,4]. It is no easy matter to couple models of climate change and the carbon cycle, but this is what Cox *et al.* have done.

In their first simulation, they projected how much carbon would be taken up by the land biosphere and ocean if climate remains constant, as in previous studies. They predefined emissions of CO_2 at the ‘business-as-usual’ (IS92a) emission scenario[5]. This model predicts that the land biosphere will take up 450 Pg of carbon over the coming century, and the ocean 300 Pg, a grand total of 750 Pg (P is peta, 10^{15}) (Fig. 1). At an average of 7.5 Pg C yr^{-1}, this is about 50% more per year than the estimated present uptake. The primary mechanism for the land uptake is increased photosynthesis resulting from the increase in atmospheric CO_2 (CO_2 fertilization). In the ocean, it is carbon dissolution of the excess atmospheric CO_2 in the surface waters and transport to depth.

Cox *et al.* then carried out a global warming simulation with atmospheric CO_2 predefined at the IS92a concentrations predicted by a model without climate warming[5]. The reason for doing this was to provide a baseline for how much warming their model would project if there were no feedbacks between climate and the carbon cycle. The projected warming is 5.5 °C over land. A simulation of

Model	Mean surface warming in 1860–2100 Global (land)	CO_2 in 2100 (p.p.m.)	Carbon uptake in 2000–2100 (Pg C)	
			Land	Ocean
1. Predefined CO_2 emissions without global warming	0.0 °C (0.0 °C)	700	450	300
2. Predefined CO_2 concentration with global warming	4.0 °C (5.5 °C)	713	-60	250
3. Predefined CO_2 emissions with global warming	5.5 °C (8.0 °C)	980	-170	400

Figure 1 **Global warming and the results of carbon-uptake simulations. Uptake is the amount of carbon absorbed from the atmosphere by 'sinks' on land and in the oceans. Previous studies have typically estimated the concentrations of atmospheric CO_2 for a given emission scenario with models that do not include the effects of global warming on the carbon sinks. The first simulation indicates that such a model based on the IS92a 'business as usual' scenario[5] puts 750 Pg C into the land and ocean. The second shows that the atmospheric CO_2 projected by such a model will lead to a warming of 5.5 °C over land. But a cross-check on the carbon budget reveals that only 190 Pg C is taken up, mainly because of the effect of warming on the land sink. The third simulation reveals that if the 'missing' 560 Pg C is put back into the model, most of it ends up in the atmosphere. In consequence, warming over land increases to 8.0 °C. (Adapted from ref. 1 with further results from P. M. Cox.)**

Daedalus

David Jones

David Jones, author of the Daedalus column, is indisposed.

how much CO_2 the land biosphere and ocean take up with this climate change provides a check on the consistency of the approach of separately simulating climate and the carbon cycle. The result is dramatic. The land biosphere is projected to be a source to the atmosphere of 60 Pg C over the next century, and the uptake by the ocean drops to only 250 Pg. The combined uptake is only 190 Pg C instead of the 750 Pg C predicted by the first study.

Cox and colleagues' final simulation coupled the climate and carbon-cycle models to find out where the carbon goes. The answer is the atmosphere. This simulation projects an atmospheric CO_2 concentration of 980 p.p.m. in 2100, rather than the 700 p.p.m. that comes from the model without climate change. The land biosphere releases 170 Pg of carbon in this model, whereas the ocean takes up 400 Pg of carbon for a total carbon uptake of 230 Pg, only slightly larger than that in the second model. The impact of this increased atmospheric CO_2 on climate is large: warming of 8.0 °C over land, 2.5 °C greater than the climate model with predefined CO_2.

How good are these estimates? The simulations of Cox *et al.* that include climate feedbacks give a larger uptake of carbon by the ocean than those without feedbacks. But this is primarily because the rate of increase of CO_2 in the atmosphere dominates the ocean carbon sink[6]. A comparison of the oceanic uptake between the first and second simulations shows a reduction of more than 20% in the ocean carbon uptake resulting primarily from global warming.

Other models allow further comparisons. A set of simulations with predefined atmospheric CO_2 using the IS92a scenario in four different climate models[7–10] gave a range in oceanic uptake of 240–470 Pg during the next 100 years (C. Le Quéré, personal communication). The large range of estimates is primarily due to differences in the transport mechanisms that remove carbon from the surface ocean and carry it to the abyss. But how the ocean circulation and biosphere will respond to global warming is poorly understood. So the finding that these two effects tend to cancel[3,8,10] must be treated as provisional.

What about the land sink? Cox and colleagues' results stem partly from a dramatic collapse of the Amazonian rainforest because of increased dryness, and partly from a global increase in respiration of organic matter in warmer soils. Here, however, there are especially large uncertainities. For example, a comparative study of the United States[11], using various sets of models, estimated that a doubling of CO_2 would change carbon content by anywhere between +32.3% and −39.4%. The lower limit stems from a projected decrease in forested area and increase in water stress; the higher limit from a projected increase in forested area and more vigorous cycling of nitrogen in soils due to warming.

Another group[12] has compared the next generation of land biosphere simulations, in which models of vegetation extent are coupled to models of biogeochemistry. The range of carbon uptake is comparable to the results from the ocean models (240–500 Pg of carbon over the coming century). But only one climate model was used. Moreover, these simulations[11,12] do not include the direct effects of land vegetation on climate, which tend to increase warming.

But perhaps the greatest source of uncertainty in estimates of the land sink lie in assumptions about CO_2 fertilization and the temperature sensitivity of soil respiration. These responses determine Cox and colleagues' conclusions. But we cannot yet be confident that they will be the dominant mechanisms over the coming century.

For instance, a study[13] of forests in five US states failed to find substantial growth enhancement from CO_2 fertilization, implying that other processes are counteracting the fertilization effect. Without CO_2 fertilization, the projected land carbon sink would disappear and soil respiration would dominate. Forest regrowth will help to compensate for this effect. The regrowth sink will decrease with time, however, whereas that due to CO_2 fertilization in Cox and colleagues' model remains strong throughout the century. On the other hand, the temperature sensitivity of soil respiration used in these models, which is the main route for release of carbon, may not hold over the longer timescales of global warming projections[14].

A final illustration of how complex things are comes from another paper in this issue (page 187)[15]. Betts suggests that increasing the terrestrial uptake of carbon by planting forests may actually increase global warming in some high-latitude regions. The reason is that darkening of the Earth's surface by trees leads to greater absorption of sunlight.

The bottom line, however, is this. Cox and colleagues' estimate that, by 2100, global warming will result in an extra 600 Pg C in the atmosphere because of a reduction in carbon sinks, an average of 6 Pg C per year. What could this mean in economic terms, given the drive to reduce carbon emissions to the atmosphere? The cost of capturing and storing CO_2 from power plants has been estimated to be about \$200 per ton of carbon emissions avoided[16]. Setting aside technological progress that might well reduce this cost, and the possibility of reducing CO_2 emissions, the cost of compensating for a 6 Pg C annual loss in carbon sinks would be around \$1.2 trillion. This calculation, simplistic though it may be, shows what is at stake. ■

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1. Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A. & Totterdell, I. J. *Nature* **408,** 184–187 (2000).
2. Houghton, J. T. *et al.* (eds) *Climate Change 1995: The Science of Climate Change* (Cambridge Univ. Press, 1996).
3. Sarmiento, J. L. *et al. Nature* **393,** 245–249 (1998).
4. Cao, M. & Woodward, F. I. *Nature* **393,** 249–252 (1998).
5. Houghton, J. T., Callander, B. A. & Varney, S. K. *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment* (Cambridge Univ. Press, 1992).
6. Sarmiento, J. L. *et al. Glob. Biogeochem. Cycles* **9,** 121–138 (1995).
7. Bopp, L. *et al. Glob. Biogeochem. Cycles* (in the press).
8. Joos, F. *et al. Science* **284,** 464–467 (1999).
9. Maier-Reimer, E. *et al. Clim. Dynam.* **12,** 711–721 (1996).
10. Matear, R. J. & Hirst, A. C. *Tellus* **51B,** 722–733 (1999).
11. VEMAP Members *Glob. Biogeochem. Cycles* **9,** 407–437 (1995).
12. Cramer, W. *et al. Glob. Change Biol.* (in the press).
13. Caspersen, J. *et al. Science* (in the press).
14. Giardina, C. P. & Ryan, M. G. *Nature* **404,** 858–861 (2000).
15. Betts, R. A. *Nature* **408,** 187–190 (2000).
16. Ishitani, H. *et al.* in *Climate Change 1995: The Science of Climate Change* (eds Houghton, J. T *et al.*) 587–647 (Cambridge Univ. Press, 1996).