The Culpable Inability Problem for Synchronic and Diachronic ‘Ought Implies Can’

Alex King (University at Buffalo)

forthcoming in Journal of Moral Philosophy

(The following is a pre-print. Please cite the final version once it is available.)

Abstract. My paper has two aims: to underscore the importance of differently time-indexed ‘ought implies can’ principles; and to apply this to the culpable inability problem. Sometimes we make ourselves unable to do what we ought, but in those cases, we may still fail to do what we ought. This is taken to be a serious problem for synchronic ‘ought implies can’ principles, with a simultaneous ‘ought’ and ‘can’. Some take it to support diachronic ‘ought implies can’, with a potentially temporally distinct ‘ought’ and ‘can’. I will argue that this problem is not avoided by diachronic ‘ought implies can’.

There are many different principles that fall under the general heading ‘ought implies can’. For each principle, different considerations will support it or tell against it. Many think that there is something fundamentally right about such a principle, and one finds casual appeals to ‘ought implies can’ throughout philosophy. As such, much of the debate surrounding this principle boils down to which version of it we should accept.¹

For example, one might take ‘ought’ to be moral obligation, ‘implies’ to be entailment, and ‘can’ to be physical ability. Clearly the support for this ‘ought implies can’ principle will be different from one on which ‘ought’ is the all-things-considered ‘ought’, or one on which ‘can’ is nomological possibility.

In this paper, I will be interested in a common worry for what I will call synchronic ‘ought implies can’ principles, i.e., those on which the ‘ought’ and the ‘can’ must obtain simultaneously. The worry is that we can sometimes intentionally make ourselves unable to fulfill obligations that we recognize ourselves as having, that we are sometimes culpably unable. This well-recognized worry provokes different responses. Some, on this basis,

¹ Though admittedly not all. Some simply argue against or cast doubt on the principle itself. See, for recent examples, Peter Graham, “Ought and Ability” (Philosophical Review 120 (2011): 337-382); Christopher Jay, “Impossible Obligations are not Necessarily Deliberatively Pointless” (Proceedings of the Aristotelian Society 113 (2013): 381-389); and Alex King, “Actions that We Ought But Can’t” (Ratio 27 (2014): 316-327).
reject ‘ought implies can’. This response is rightly seen as too hasty by others, who instead revert to more accommodating versions of ‘ought implies can’. One common candidate among these is a version of the principle that I will call diachronic, since it allows the times at which the ‘ought’ and ‘can’ obtain to be distinct. I will argue that the culpable inability problem for synchronic ‘ought implies can’ is not avoided by diachronic ‘ought implies can’. More precisely, I will argue that there are parallel cases that a diachronic version cannot avoid, so that we cannot say, on the grounds of such examples, that either is on a better footing than the other.

To be clear, though, this paper does not take a stance on whether culpable inability is a knock-down argument against synchronic ‘ought implies can’ views. This paper will argue that if it is a problem for synchronic views, it is also a problem for diachronic views. That is, this strategy of response to culpable inability is not a good one because it runs into an analogous problem.

Furthermore, because this paper provisionally grants that culpable inability does pose a problem for synchronic ‘ought implies can’ views, I will take for granted a couple of the common elements of such views assumed in those discussions. In particular, these debates suppose that the relevant ‘ought’ can be understood as moral obligation and that the ‘implies’ is an entailment. The ‘can’ is sometimes understood as an ability, and sometimes as possibility of some kind (which is not always specified, but is typically something weaker than logical possibility – perhaps metaphysical or physical possibility). This paper will remain neutral about which of these alternatives is most appropriate.

In Section 1, I will present and distinguish the synchronic and diachronic versions of ‘ought implies can’. Section 2 will present the culpable inability worry for the synchronic version, and Section 3 will present

---

2 See, e.g., Richard Robinson, “Ought and Ought Not” (Philosophy 46 (1971): 193-202), 197, and Walter Sinnott-Armstrong, “‘Ought to have’ and ‘could have’” (Analysis 45 (1985): 44-48), who argues further that the diachronic version is not really ‘ought implies can’.


4 For diachronic versions motivated this way, see Brouwer 1969 (46-47), Stocker 1971 (316), Howard-Snyder 2006, and Copp 2008.
the central argument: a dilemma for the diachronic version. It is either too weak a principle to explain many central cases, or culpable inability problems arise in a way that threatens it every bit as much as the synchronous version. In doing this, my paper has two aims: one, to underscore the importance of recognizing differently time-indexed versions of ‘ought implies can’ and offer a semi-formal schema for distinguishing various views; and two, to put this to work in the case of the culpable inability problem.

1. Synchronic and diachronic

‘Ought implies can’ says that, for any subject S and action A,

**Ought Implies Can**

If S ought to A, then S can A.

But we need time indexes – in fact, we have the potential need for three: one for the ‘ought’, one for the ‘can’, and one for the action. Thus,

**Ought Implies Can, Time-indexed**

\((\forall t_o)(\forall t_a)(\exists t_c)(S \text{ ought at } t_o \text{ to } A \text{ at } t_a, \text{ then } S \text{ can at } t_c \text{ A at } t_a),\)

or equivalently,

\((\forall t_o)(\forall t_a)(S \text{ ought}_{t_o} \text{ to } A_{t_a}, \text{ then } S \text{ can}_{t_c} A_{t_a}),\)

where \(t_o\) is understood as the time of the ‘ought’, \(t_a\) is the time of the action, and \(t_c\) is the time of the ‘can’. These say roughly that, if an individual ought at some time to do something at some (potentially different) time, then there is some (possibly third) time at which that individual can do it. Toward the end of the section, we
shall see that, because English modal verbs are messy, even this somewhat tortured prose formulation is unclear and does not capture the generality that we would like. But for now, let us examine why we need three separate indexes. Remember that the current task is simply to offer a framework for understanding different versions of ‘ought implies can’, not to decide on any particular one. So we need to accommodate a variety of different ways that one might think ‘ought’, ‘can’, and actions line up.

Start with the time of the ‘ought’, $t_o$, and time of the action, $t_a$. If a friend borrows a book from me and promises to return it when I see her one week from today, she creates an obligation now (and thus ought now) to return the book in one week. This obligation continues to stand over the next seven days, so that tomorrow, she still ought (then) to return the book six days from then. Of course, in some cases $t_o$ and $t_a$ are simultaneous, but our formalization should remain neutral about whether this holds for all cases.

There are plausibly also situations where the time of the ‘can’, $t_c$, is distinct from the time of the action, $t_a$. It is plausible that, in normal circumstances, my friend can now return the book in one week. Maybe this means something like, at this moment, she can ensure that she returns the book one week from today. There is in some sense a path from here to there, i.e., from where she is now to her returning the book in one week, that is not hugely improbable. Spelling this out exactly is beyond the scope of this paper, but there is undoubtedly a plausible and live view on which one can at one time perform some action at another time.

More controversially, the time of the ‘ought’ and the ‘can’ ($t_o$ and $t_c$) may come apart. Using this, we can distinguish between two ‘ought implies can’ schemas, which we can call synchronic and diachronic. Synchronic schemas will require that the ‘ought’ and ‘can’ are simultaneous.

**Synchronic ‘ought implies can’**:

$$(\forall t_o)(\forall t_a)(\text{If } S \text{ ought at } t_o \text{ to } A \text{ at } t_a, \text{ then } S \text{ can at } t_o \text{ A at } t_a)$$

This is a version of the original schema

$$(\forall t_c)(\forall t_a)(\text{If } S \text{ ought at } t_o \text{ to } A \text{ at } t_a, \text{ then } \exists t_c[S \text{ can at } t_c \text{ A at } t_a])$$
where \( t_c \) must equal \( t_o \). Thus we could, equivalently, replace the \( t_o \)s with \( t_c \)s, or add a clause to the effect that \( t_o \) equals \( t_c \). Furthermore, although it will not be relevant for the subsequent discussion of culpable inability, one might make a further distinction between a stronger and a weaker synchronic ‘ought implies can’. According to the stronger, the time of the action would also be the time of the ‘ought’ and ‘can’; according to the weaker, the action could be indexed to a different moment. But the common thread shared by any synchronic view is that there is no moment when one ought to do something but cannot. Any flicker of inability causes a corresponding flicker in what one ought to do.

The diachronic schema of ‘ought implies can’ is less restricted.

**Diachronic ‘ought implies can’**: 
\[
(\forall t_o)(\forall t_a) (\text{If S ought at } t_o \text{ to A at } t_a, \text{ then } \exists t_c [S \text{ can at } t_c \text{ A at } t_a]).
\]

This is sometimes called ‘ought implies could have’, since one loose but intuitive way of rendering it in English is to say that, if someone ought to do something, then they could have done it.\(^5\)

Here, there is no constraint that \( t_o \) and \( t_c \) be the same, though no constraint that they must always be different.\(^6\) The diachronic version allows the time indexes of the ‘ought’ and the ‘can’ to come apart. Motivating this separation is the idea that you might now make it the case that you are later unable to fulfill an obligation that you then have. This is the kernel of the culpable inability problem that we will address in the next section.

So far, we have seen the need for, potentially, three different times: one for the obligation, one for the ability, and one for the action. Different ways of assigning these will give us importantly different versions of ‘ought implies can’.

---

\(^5\) See, e.g., Sinnott-Armstrong 1984 and 1985 for this term. It is to be distinguished from a view that some defend that we might gloss as ‘ought to have implies could have’, viz. a synchronic view. See for the latter Michael Zimmerman, “Remote Obligation” (American Philosophical Quarterly 24 (1987): 199-205) and Bart Streumer “Reasons and Ability” (in D. Star (ed.), The Oxford Handbook of Reasons and Normativity, Oxford: Oxford University Press (forthcoming)).

\(^6\) It would thus be more accurate to call it ‘ought implies can or could have’.
Before continuing, it is worth noting two things. First, though I have been calling \( t_0 \) the time index of the ‘ought’ or of the obligation, strictly speaking this is too narrow. If, for example, we are interested in a contrapositive ‘ought implies can’ principle, we are interested in how an inability at \( t_0 \) could result in a lack of obligation at \( t_0 \). So we could more accurately consider \( t_0 \) the time, not of the ‘ought’ or obligation (since that builds in the assumption that such an ‘ought’ or obligation arises), but of the putative or prima facie ‘ought’ or obligation under consideration.

Second, though we have been indexing to particular moments, this framework allows us to accommodate ranges of times. This is easy enough to accomplish, but requires a little more machinery. Suppose that my friend has an obligation \textit{the entire week} to return my book \textit{one week from today}. So \( t_s \) ranges from now to one week from now, and \( t_a \) is one week from now. Sometimes, there is also a range during which the action can be performed. When we meet for lunch in one week, my friend will be able to return the book anytime for the duration of our lunch. So \( t_a \) ranges from the start of our lunch to the end of it. Given that, we should understand the times as working in the following way in the formulation of ‘ought implies can’: If S ought, for some time interval \([t_{01}–t_{02}]\), to A at \( t_a \), then there’s some time interval \([t_{c1}–t_{c2}]\) during which S can A at \( t_a \). The synchronic interpretation will say that any lapse in the latter interval will create a corresponding lapse in the former; while the diachronic will be more lenient. For simplicity, I will not address this possibility in what follows, but the same arguments could be made with time intervals instead of instants.

2. \textit{The Old Problem: Culpable Inability and Synchronic Views}

The problem can be seen in the following case.

\textit{Café delinquent}. A woman goes to a café and, after ordering but before receiving the check, gives all her money to a friend, who then leaves the café.
This is a case of culpable inability, of self-sabotage or self-imposed inability, where someone fails to do what she ought because of prior misbehavior. The café delinquent fails to pay before or upon leaving the café.

The common, and natural, way to read this case is that the woman cannot, after she gets rid of her money, pay the check. Nevertheless, after she receives the check, she violates an obligation to pay it (before leaving the café). That is, she does something she ought not. But according to the synchronic version, she has not violated an obligation after receiving the check, since she could not have had this obligation after giving away her money, i.e., the moment when she became unable to fulfill it. This is obviously a cost for synchronic ‘ought implies can’.

Common similar examples include grooms who board planes prior to their wedding ceremonies and debtors who squander their money prior to the debt repayment deadline. In all of these cases, it seems like the individuals fail to do what they ought to even after they become unable to do it. But this can’t be true if the ‘ought’ goes away when the ‘can’ does.

There is an additional cost, one that is less obvious at first glance. The synchronic view is committed to saying that, in getting rid of the money, the café delinquent does not actually violate her obligation to pay upon leaving. In fact, she never violates that obligation. Instead, she makes it disappear. A defender of the synchronic version can always say that a different obligation is violated, perhaps the obligation to ensure that she is able to pay upon leaving. So, with respect to this obligation at least, she has done something wrong. But her obligation to pay upon leaving is not violated; it just goes away.

To repeat, I am by no means saying that this is the final word on synchronic versions of ‘ought implies can’. I only mean to point out the objection as it stands. Those who wish to defend the synchronic version have some resources to do so. But many have taken this objection very seriously, and even taken it to straightforwardly refute synchronic views, or indeed even to refute ‘ought implies can’ altogether.

---

8 See fns. 2, 3, 4.
3. The New Problem: Culpable Inability and Diachronic Views

Those who take this seriously have sometimes moved instead to a diachronic version of ‘ought implies can’, which is meant to solve the problem. In Café delinquent, it seems that, after receiving the check, she still fails to do what she ought, i.e., pay it then. But of course it was true at some prior time that she could have (made it the case that she) paid the check. It is only due to self-sabotage that she cannot do so. A principle advantage of the diachronic version is that it allows for these ‘ought’ and ‘can’ intuitions to be true. Recall that the diachronic schema says:

\[(\forall t_o)(\forall t_a)(\text{If } S \text{ ought at } t_o \text{ to } A \text{ at } t_a, \text{ then } [\exists t_c][S \text{ can at } t_c A \text{ at } t_a]).\]

So, if the woman ought after receiving the check to pay it (then), then there is some time at which she could have (made it the case that she) paid it. In particular, it was true at before giving her money away that she could have paid after receiving the check – if only she hadn’t given the money away. This looks like a ready and easy fix for the original problem.

My worry is that we can recast the culpable inability problem so that it applies to diachronic ‘ought implies can’, too. Culpable inability cases all rest on there already being something one ought to do, and one subsequently making oneself unable to perform it. But I think we can generate the same problem when we see an ‘ought’ coming down the road – when we see that there will, given certain conditions, be something that we ought to do, but we make ourselves unable to do it.

We can alter Café delinquent to bring out this worry.

*Café delinquent* 2. Suppose that the delinquent, instead of ordering and then giving the money to her friend, gives the money to her friend then orders.
In a way parallel to the earlier culpable inability examples, it is still natural to say that she ought to pay, although she cannot. Or at least, it is equally as natural as it was before. This minor change does not seem to affect the situation in a morally significant way. She still fails to do what she ought when she fails to pay the check. So, to the extent that problem in the original Café delinquent case was compelling, Café delinquent 2 is also compelling.

The parallel is especially hard to deny if we assume, in the original case, that she had been planning all along to give her money to her friend so that she would not be able to pay. In both cases, she sees an obligation coming down the road and intentionally makes herself unable to fulfill that obligation. It is just that in the synchronic case, the obligation has already kicked in; in the diachronic case, it has yet to.

So far, none of this is a problem for the diachronic view. Indeed, diachronic ‘ought implies can’ initially seems to capture such cases. After all, there is a time \( t_c \) such that the delinquent could have paid upon leaving the café, namely, any time prior to ditching the money. But this introduces a dilemma about how to characterize the diachronic view.

On the one hand, we can let \( t_c \)’s range include times before the ‘ought’ arises, i.e., allow \( t_c \) to precede \( t_o \). This version would, however, be too inclusive, and therefore fail to do all the explanatory work we want ‘ought implies can’ to do. There are many things we could have done or been in position to do that we nevertheless want ‘ought implies can’ to get us out of, but the diachronic version won’t be able to get us out of all of them. Let’s assume that, if I notice someone walking past who has just dropped his wallet, I ought to return it to him. So let \( t_o \) be the time when he drops the wallet (or perhaps when I notice). Suppose furthermore that it could have been you, instead of me, walking behind him today. You could have been in position to see his wallet fall, and thus it could have been you, instead of me, not only in position (both physically and epistemically) to return it to him, but it could have been you who was obligated to return it to him. That does not mean that you are now obligated to return it to him. That would be absurd. You are not now obligated to, and—here is the key thing—it seems like the reason you are not now obligated to is because you cannot.

Of course it is not necessarily true that, if you were walking behind him today, you would in fact have seen him drop his wallet and you would in fact have been able and obligated to return it to him. All sorts of other things might have gotten in the way at any of these points. However, it remains true that you could have
seen him drop it, and *could have* been able and obligated to return it to him. And this is all that we need for the example to pose a problem.

To be clear, this is not meant to be an argument against ‘could have implies ought’, rather than ‘ought implies could have’. The point is not that, because you could have been there, you ought to return his wallet; but that this is absurd, and therefore ‘could have implies ought’ is wrong. I admit that the wallet example also shows that ‘could have implies ought’ is wrong, but I think it says something important about the diachronic ‘ought implies can’ principle.

It is the job of the right ‘ought implies can’ principle, whatever it turns out to be, to rule out implausible verdicts that result from things like inability or impossibility. Here, it intuitively looks as if you are not obligated to return his wallet, and that the reason you are not obligated to return it is that you are not there, because your not being there makes it the case that you cannot return it. In other words, we want to use something ‘ought implies can’-like to explain why you are under no such obligation. But diachronic ‘ought implies can’ cannot help us because you could have been there, and thus you could have returned it. (Recalling that diachronic ‘ought implies can’ is more helpfully rendered as ‘ought implies can or could have’ does not help here, either. Although it is true that you cannot return it to him, it is still true that you *could have* returned it to him, it is therefore also true that either you could have returned it to him or you can return it to him.)

I have been assuming that the best explanation of why you are not now obligated to return the wallet is that you cannot do so. A defender of the diachronic ‘ought implies can’ might, however, object that the reason you are not obligated to return the wallet is that you are unaware of the situation. This is quite different from saying that you can or cannot, so the defender of diachronic ‘ought implies can’ may object that it is not any sort of ‘ought implies can’-like principle at work. Thus, in short, the fact that their preferred principle cannot explain the case is no worry at all.9

This is a fair concern to have with the wallet case as it stands. But we can, by looking at a couple of variants on this case, see that the problem remains even if we add in the relevant knowledge.

---

9 Thanks to a referee for this journal for raising this point.
First, suppose that the situation is as above, except for two things. One, I become unable to return his wallet (he gets into a taxi and the wallet drops down a sewer drain). Two, I call you after I see this all happen. You now know that he has dropped his wallet. This doesn’t seem to change anything about your obligations regarding the man and his wallet. You are still under no obligation to return it. We can see that it is precisely your inability to return the wallet that prevents your having an obligation to return it in the following way.10 If we imagine that you could return the wallet, then plausibly you would be under such an obligation (assuming you had no conflicting, stronger obligations, etc.). Maybe you just so happen to be down in the sewers at that moment, can grab it, and can use the information inside to contact him. This highlights the fact that it is your lack of ability, and not your lack of knowledge, that precludes your obligation. To underscore the point, it remains true in this variation that you are not obligated to return the wallet, and that the best explanation for this is your inability to return the wallet. Nevertheless, you could have been able to return it (as shown by imagining that, counter to fact, you are currently in the sewer and can retrieve the wallet), so diachronic ‘ought implies can’ doesn’t do all we want it to.

What happens when we expand your knowledge even further? Suppose that you somehow divined—or inferred through sophisticated behavioral analysis (and a possibly unsettling amount of information)—that this man would drop his wallet today. You also divined or inferred that I would be there, behind him, and would be able to pick up and return his wallet. You knew that you could have been at this place at the right time, and if you had, you’d have been able to return the wallet too. But suppose that you didn’t alter your behavior given this knowledge, and that you are now, as in the other variations, in a different place and are now unable to return his wallet. Are you now under an obligation to return his wallet to him? It seems the answer is still no. And it doesn’t matter whether you were good-hearted in your motivations (you knew I’d return it anyway so no need for a redundancy) or ill-willed (you knew I’d return it, but you’d have rather the guy lose his wallet anyway). Regardless, you seem now to be under no obligation to return his wallet, given that you cannot now do so, and despite the fact that you could have been there and could have returned it yourself.

10 This strategy follows Graham 2011, 372.
In short, the reason that you are not obligated cannot be some lack of knowledge, because even when we adapt the above examples to include the relevant knowledge, you still lack the relevant obligation. Hence the best explanation for your lacking the relevant obligation is not a lack of knowledge, but a lack of ability.

This problem is more pervasive than it might seem. Compare, for example, Peter Graham’s observation\(^\text{11}\) that the reason that one does not have the obligation to snap one’s fingers and make world suffering disappear is because one cannot; or relatedly, that the reason one does not have an obligation to save a drowning child many miles away is because one cannot do so. While it is true in the first case that one never could have snapped one’s fingers and made world suffering disappear, it might well be true that one could have saved the drowning child – if one could in fact have been there at just that time. Any case that mirrors the drowning or wallet cases will be difficult to capture. And if our candidate ‘ought implies can’ principle cannot explain these central cases, it misses a very important explanandum.

So this horn of the dilemma, on which we allow \(t_c\) to precede \(t_o\), looks bad. What about the other horn, where \(t_c\) kicks in only once the ‘ought’ is in place, so that \(t_c\) cannot precede \(t_o\)?

The problem is that, then, we are in exactly the same situation as the synchronic version was. In *Café delinquent 2*, it is intuitive (as intuitive as it is in the original *Café delinquent* case) that an obligation arises. But the diachronic version, on this horn, implies that there is no time at which the delinquent could have paid, since \(t_c\) cannot precede \(t_o\). In other words, an obligation seems to arise, but the diachronic version is as ill-equipped to accommodate this obligation as the synchronic version was before.

The problem is that, then, we are in exactly the same situation as the synchronic version was. In *Café delinquent 2*, it is intuitive (as intuitive as it is in the original *Café delinquent* case) that an obligation arises. But the diachronic version, on this horn, implies that there is no obligation. Why? An obligation to pay would normally arise upon her ordering at the café, but there is no time after that (that is, no time \(t_c\) after \(t_o\)) at which she could have paid. This is because, on this horn, \(t_c\) cannot precede \(t_o\). In other words, an obligation seems to arise, but the diachronic version is as ill-equipped to accommodate this obligation as the synchronic version was before.

---

\(^{11}\) Graham 2011, 372.
As before, we incur the additional cost that the synchronic view had, namely, that in getting rid of the money, the delinquent does not violate her obligation to pay upon leaving. She never violates that obligation, because there is no time \( t_0 \) at which she could have paid. Instead, she precludes the obligation from arising by giving away her money before ordering.

A defender of the diachronic version may, too, argue that Café delinquent 2 commits an additional wrong by engaging in her self-sabotaging act. Or perhaps, the wrong is ordering-without-sufficient-funds. If this is true, the diachronic view can explain why it would be wrong (because she could have avoided ordering-without-sufficient-funds). So, as above, we want to say that she has committed a wrong by not paying the check, and we can leave space for an additional obligation that has been violated. But just as before, her obligation to pay upon leaving is not violated; it just goes away.

I take no stand on whether these are acceptable responses. For present purposes, what is important to notice is that, in offering such a response, we rely on the very same defense strategy that was available to the synchronic version. The synchronic version is committed to the view that the obligation does not really persist past the inability to fulfill it. Its defenders can also try to explain why it is not so bad to be committed to this. But what we are trying to assess here is whether the diachronic version is dialectically superior to the synchronic version, given the culpable inability worry for the synchronic version. So we are assuming that the culpable inability worry persists despite that response, since this worry is what motivated moving to the diachronic version in the first place. But if an analogous response is all the diachronic version can offer us, then we should be just as worried as we were about the synchronic version. At the end of the day, moving in this direction has offered us no real refuge from the original culpable inability problem, which reappears in a slightly altered form.

This paper has had two aims. The first was to introduce a useful, semi-formal framework for discussing different versions of ‘ought implies can’ that recognizes the importance of having at least three different time indexes. The second was to put this framework to use in the case of the culpable inability problem. A dilemma arises for the diachronic ‘ought implies can’ principle once we ask how to restrict these time indexes. On the first horn of the dilemma, it is too weak to explain a central class of cases where we want to invoke ‘ought implies
can’. On the second horn, it is on the very same footing as the synchronic version. None of this is to say that diachronic ‘ought implies can’ is false, nor even to say that synchronic ‘ought implies can’ is false. It is simply to say that cases of culpable inability are not sufficient reason to prefer the diachronic over the synchronic ‘ought implies can’. \(^{12}\)

\(^{12}\) For helpful conversation and comments, I owe thanks to Nic Bommarito and David Estlund, as well as audiences at the Australian National University, the National University of Singapore, the University of Sydney, and the University of Canterbury. Part of the work on this was supported by Australian Research Council grant DP120101507.