# What makes emotional experiences come to mind?

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We live in an emotive time. Around the world, many stressful events are unfolding, from Brexit here in the UK, impeachment investigations in the USA, and the seemingly inevitable catastrophe of climate change. In a recent Extinction Rebellion march a young girl carried a placard to highlight the imminent risk of massive wildlife extinction (Figure 1). Reflecting on the repercussions the photograph has for us, as members of a public where anxiety and anger about climate change are ramping up, it is, clearly, a challenge to study the brain mechanisms that render this image so memorable.


Figure 1. Young person in an Extinction Rebellion march.
*The first public event for Extinction Rebellion North Devon saw a funeral procession in Barnstaple High Street to highlight all the species that have gone extinct. Picture: Tony Gussin*

Such images may evoke an array of feelings – perhaps sadness, or even outrage. These feelings are accompanied by physiological reactions that include hormonal and bodily changes, such as increased blood pressure, part of the fight or flight response. Cognitively, our brains evaluate it to be a novel picture, and in the context of this publication, unexpected; therefore, it grabs attention seemingly involuntarily. We may find that, after the first instance, we also choose to allocate attention to it, and elaborate on its meaning, connecting it to other news events, and to schemas we have, be it about demonstrations, or about teenagers.

To study memory for emotional experiences in the laboratory I must reduce the richness of a real-life experience. Photographs represent an acceptable balance, allowing for some experimental control while remaining complex and evocative. It is also ecologically valid to study memory for photographs, because we are exposed to such materials all the time. Typically, I show healthy adult

research volunteers sequences of 10-15 distinctive scenes, some emotionally negative (scenes of crime and violence), and others neutral (domestic scenes of people hanging out at home, or doing work around the house). Each picture in the sequence is presented for a few seconds, and there are a few seconds of break before the next picture is presented. At the end of the sequence participants are distracted for about a minute with an irrelevant task, to decrease influences of rehearsal. They are then invited to describe the pictures they can remember in whatever order they come to mind. For example, to describe the picture in Figure 1 they may say – "*a teenager marching in a demonstration*". This free recall task , mimics real-world remembering, when we tell friends and family about our day. Many researchers find that in a task like this, participants typically recall, on average, more of the emotional pictures than the neutral pictures. In my research I have also observed that participants typically recall the emotional ones before the neutral ones.

Emotion is a difficult concept to define scientifically. There are a number of frameworks for research of emotion, which are not very well integrated. One of these suggests that emotional experiences can be classified according to how happy or unhappy they make us feel, and how intense these feelings are. According to that framework, the feelings I have when viewing the photo in Figure 1 are negative in valence and high in arousal. Another framework discusses emotional experiences according to their relationship to our goals. The picture at the top is relevant to my goals, and incongruent with them – I really would prefer that young people did not have to fear for their future in a world that previous generations damaged beyond its capacity to sustain life as we know it. Broadly, goal-relevance and goal-congruence are linked to emotional arousal and valence. Accordingly, understating what aspect of emotion result in good memory, is if paramount interest. Evidence suggests that emotional arousal, rather than the many other aspects of complex picture scenes, is the features of the experience that has the largest influence on memory.

To check whether this is the case, I developed a different task with professor Nathaniel Daw from Princeton, and an undergraduate student intern, Deimante Kavaliauskaite. Together, we adapted

a task called the 'value-directed remembering' task. Research participants were presented with a sequence of neutral objects, such as a hat, a telephone, a paperclip. Some objects were presented surrounded with a grey frame. Participants were told that if they recall the framed objects, they would received one pound, and if they recall other objects they would receive 10 pence. This task resembles the picture task discussed above in the sense that like emotional pictures, the promise of high monetary reward is relevant to the participants goals (to gain money) and, therefore, it may trigger (mild) emotional arousal, compared to the control condition where only low reward was available. If the degree of emotional arousal/goal relevance is what matters for the effect I observed with emotional pictures, then I should find a similar memory enhancement effect in this task. Indeed, when participants view a sequence of framed and unframed pictures of objects they recall more of the framed ones, on average, and also tend to recall them first.

Is it possible to be more specific about the mechanism that allows emotional arousal to influence memory in this task. We have seen that at the time photographs (or real-life experiences) are encoded, there are many differences between emotionally-arousing and neutral ones. These differences should render emotional experiences quite distinct from other representations stored in our memory, and which would help them win the competition for retrieval against less distinct representations. For these reasons, I became interested in the influence of emotion on encoding, retrieval, and their interplay. Yet the majority of work in the field does not focus on the influence of emotion on encoding and retrieval, but on the way emotion influences the maintenance - or long-term consolidation - of neural traces of experiences during the hours that follow the experience. There is good evidence from non-human animal models that maintenance is more efficient when the experience was emotional. Yet on its own, influences of emotion on maintenance cannot account for the pattern of findings I observed in my free recall task, because I tested memory a mere minute after encoding, before long-term maintenance processes could influence the results. I hypothesized, therefore, that cognitive processes during encoding, which are read out through their influence on immediate memory in my task, also give rise

to the unique physiological changes that take place after encoding is completed and improve maintenance.

As a memory researcher, I suspected I could learn more about the interaction between emotion and memory by referring to some of the established cognitive-computational models of memory in the literature. These, however, focused on memory for single neutral words, so it was not immediately apparent how they can be used to study emotional effects. I was curious to find out how emotion modulated the mechanisms specified by these models, believing that understanding this influence will help me connect the literature on emotion and emotional memory to the mainstream literature on memory, with its proud, over a century-long history.

One on of the obvious differences between emotional and neutral stimuli in my task is that the emotional ones stand out in the sequence. This could allow them to attract processing resources during encoding, and take those away from competing neutral stimuli. To test the influence of the distinctive-processing factor I used another method of presenting the stimuli. To clarify its rationale, its useful to reflect again on the photo in Figure 1. Within its own demonstration march it was by no means unique. In fact, the young person in the picture was preceded and followed by others carrying equally heart-wrenching pictures and messages. To mimic this situation, in the emotional pure list condition I showed participants a sequence of 10-15 emotional scenes one after the other – that is, with no neutral pictures at all. In the neutral pure list condition participants observed a sequence comprised only of neutral scenes. The experimental design thus includes two factors, manipulated within-subject: the composition of the list, and the emotionality of the picture. Across a number of such experiments I found that the emotion does not influence the ability to recall directly - the average recall of emotional and neutral pictures in pure lists is equivalent. Instead, the task yields a robust interaction between the composition of the list and the emotionality of the pictures, a pattern I refer to as the 'emotional list composition effect'. Compared to the pure neutral list condition, which could be considered a 'baseline' condition, memory for emotional pictures in mixed lists is sometimes enhanced, and memory for

neutral pictures in mixed lists is always suppressed. Similar results were obtained whether emotion is manipulated through the presentation of emotional scenes, or through the promise of monetary reward. The results of two such experiments are depicted in Figure 2.

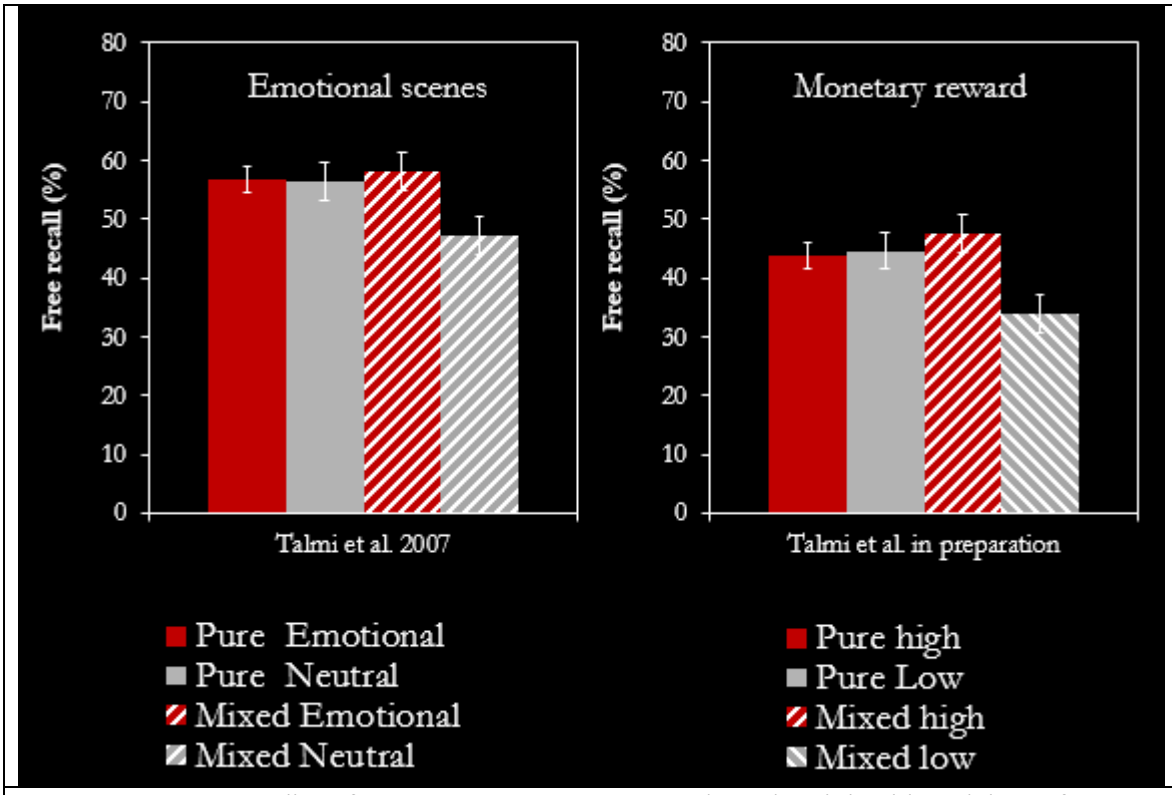


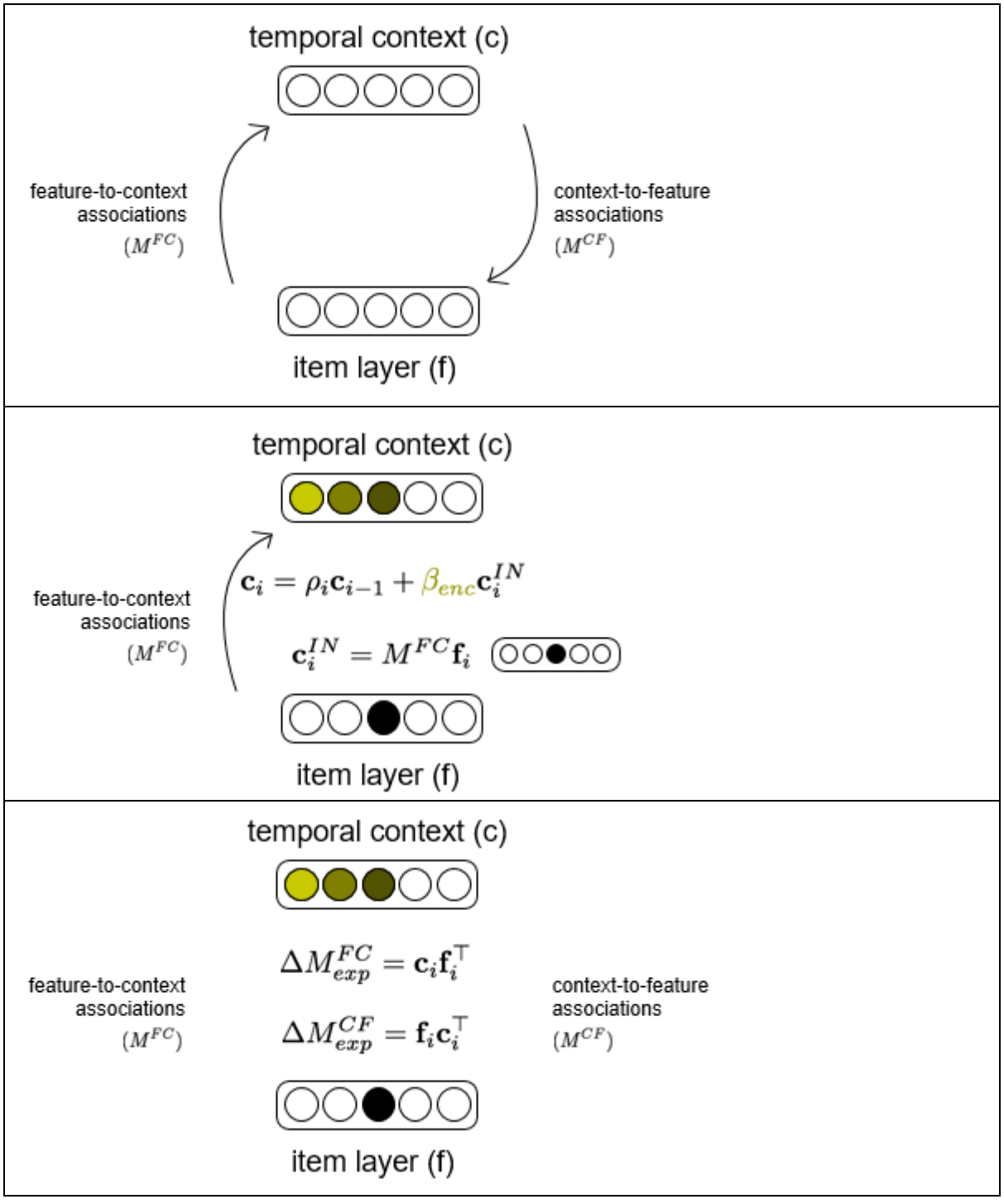

Figure 2. Average recall performance in experiments conducted with healthy adults. Left: emotion was manipulated by presenting participants with emotional or neutral scenes. Right: emotion was manipulated by presenting participants with framed items that predicted high reward and unframed items that predicted low reward.

The emotional list composition effect suggests that the distinctiveness of the emotional image in the mixed list condition plays a key role. The next issue to discover if this is because emotional pictures attract preferential processing resources in that condition, but not in the pure list condition. I have spent a few years looking for evidence to bear on this question, together with Lucy McGarry and Betty Luk, who were undergraduate students at the time, Gemma Barnacle, who was my PhD student, and Dr. Tobias Sommer-Blochl, a collaborator from the institute for experimental medicine in Hamburg. That research, using behavioural, electrophysiological, and fMRI measures of attention, suggests that emotional scenes attract preferential attention regardless of the composition of the list. This makes some intuitive sense: the photos selected for these experiment are quite different from each other. It

seems intuitively unlikely that a truly upsetting picture is not attended just because it followed another picture of a different horrible situation. The implications of these experiments, where we measured the amount of attention allocated to stimuli in the list-composition task, is that encoding resources alone cannot explain the emotional list-composition effect.

One of the most established theories of free recall is retrieved-context theory, developed by Mike Kahana and Marc Howard, from the University of Pennsylvania and Boston University, respectively. To learn more about their theory, see http://memory.psych.upenn.edu/Publications. The key concept in the theory is the temporal context, a d concept which refers to people's mental state, or brain state, and which changes gradually over time as a consequences of new experiences. The theory contends that the context of each new experience is the sum of experiences that came just before it, weighted as a function of their recency. Retrieved-context theory uses these ideas to explain why we recall the most recent things that happened to us better than things that happened longer ago (the recency effect). The recency effect occurs because when we try to recall past experiences, we use our current temporal context – our present mental state – as a probe, to cue past events that share something with where we are now. Because the current context is most similar to the most recent context (say, the context of 1 minute ago) than the more remote context (say, the context of 100 minutes ago), it is more likely, all things considered, that the most recent experiences win the competition for recall. The theory also suggests that whenever we recall something, our mental state is updated by the content we just recalled, including the original context of that content. In this way, our temporal context after we recall an experience is a little bit more like the temporal context we had at the time we encoded the original event. Consequently, once we recall one thing, it is easier to recall the experiences we had just before and after it (the temporal contiguity effect). Figure 3 depicts retrieved-context theory schematically. Retrieved context theory is implemented in a set of mathematical equations. These provide a mathematically-precise way to describe the processes I described above. These equations are implemented in a computer program which accepts, as input, to-

be-encoded items as vectors of ones and zeros, and provides, as output, items (vectors) that the model recalls. Figure 3 includes some of these equations.



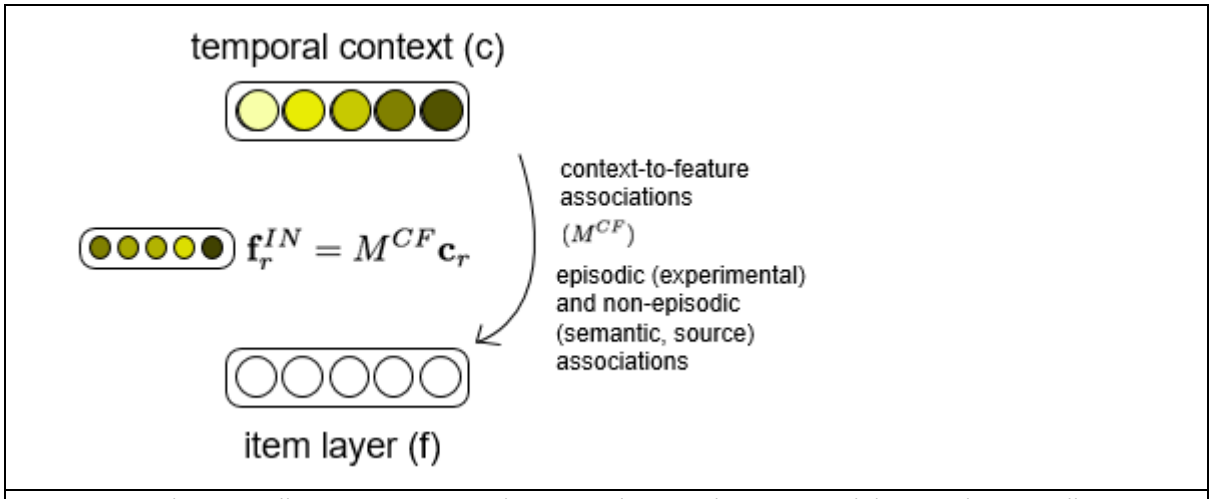



Figure 3. A schematic illustrating retrieved context theory. The top panel depicts the overall structure of the model, a 2-layer network with an item and a context layer, connected through association matrices. The next two panels depicts how the model encodes an item. The fourth panel depicts how the model recalls an item. Images courtesy of L. J. Lohnas.

But the notion of a temporal context, alone, cannot explain the emotional list composition effect, because it does not differentiate between emotional and other stimuli. To capture the emotional meaning of experiences I turned to more recent versions of retrieved-context theory, developed by Sean Polyn and Ken Norman. There, experimental stimuli are defined not only in terms of the sequence in which they were presented, but also in terms of the established associations they have with other stimuli (the *semantic context*) and in terms of the attributes they share with other stimuli (the *source context*). Had you attended the march in which the photo in Figure 1 was taken, then the people who marched before and after the girl in the picture would serve as its temporal context; the ideas you have about climate change are its semantic context; and its source context would be the context of demonstration, which it shares many attributes with.

I hypothesize that the emotionality of a picture often changes its semantic associations, but that it can also be considered a source. This is because there is something similar in the cognitive, affective, and physiological processes that occur when we view images that make us unhappy and upset, even if they do not share much in terms of their semantic meaning. This emotional similarity is a relatively new topic of investigation, which I am presently working on with my current PhD student,

Martina Riberto, and Dr. Gorana Pobric from the University of Manchester. In the value-directed-remembering task the framed pictures of objects, which, if you recall, indicate to participants the likelihood of reward, do not share specific semantic associations, but all have the same (mildly positive) emotional source. In retrieved-context theory, all of these contexts of an item matter when, at some point after study, items compete with each other for retrieval. The item with the context that is, overall, most similar to the current context is most likely to win over other items, and be recalled.

My variant of retrieved-context theory which includes emotion is called the 'emotion Context Maintenance and Retrieval' model, or eCMR for short. I spell emotion with a small e to clarify that in the lab I only study mild emotionality, and the model may well fail to describe real-world emotion, let alone real personal trauma. Rivka Cohen at the University of Pennsylvania is working with Professor Kahana on the relevance of this conceptualisation in patients with depression. The advantage of using a formal model is that it removes some of the ambiguity of the terms we use in language. For example, while above I spoke about an emotional source, the equations I implemented define the emotional sourc' of every item as the numbers that occupy two placeholders of the item vector. If one of these places is a *1* then the item is neutral; if the other place is a *1* then it is emotional. In the current variant of the model, therefore, the emotional value is coded in an 'all or none' manner. This is obviously a huge simplification, and could certainly be improved upon in future variants of the model. At present, this implementation decision has implications for the outputs of the model. In eCMR emotional items not only have an emotional source, but they are also more strongly associated to their emotional source than neutral items are. The tightness of that association, controlled by a specific model parameter, reflects the preferential allocation of attention to emotional experiences. This parameter strengthens the association between the item and context layer, denoted $M^{CF}$ in Figure 3. The increased association strength biases the output of the model because when the context layer is used to produce candidate items for recall, it would produce, with a higher probability, items that are connected to it more tightly. All else being equal, therefore, this means that when the model encodes a mix of emotional and neutral items, and is probed to recall, it is more likely to produce an emotional item than a neutral one. The

result is enhanced average recall of emotional items. However, when the sequence is entirely comprised of emotional items, they no longer have any particular advantage, because they are all tightly connected to the context layer. Similarly, neutral items do not suffer when the model recalls a pure list of neutral items. The result is equivalent levels of average recall in pure lists, be they entirely emotional, or entirely neutral. Taken together, the model naturally produces the emotional list composition effect, and clarifies how these effects may be a result of the interplay between encoding effects (increased association strength between the context and item layer) and the competitive nature of the retrieval process. The computer program that implements the model intends to mimic the workings of the mind of a research participant. To the degree that it does this well, it would recall what participants actually recall. In other words, a computational model is tested by comparing its output to empirical performance. A key success of eCMR, therefore, is that it naturally produces the empirical pattern of the emotional list composition effect. eCMR is interesting because it is able to account for an empirical pattern that no other theory is able to account for. But its value goes beyond that specific effect. Its potential is due to the fact that it is the first formal theory of the effect of emotion on memory recall.

Models are useful because they capture a particular understanding and provide a concrete prediction that can be readily tested. If future research obtains data that contradicts the predictions of eCMR, it may be developed and reshaped to fit the empirical pattern better, and encompass more accurately the processes that take place in the human mind when people encode, maintain, and retrieve emotional and neutral experiences. Models can also encourage researchers to generate novel predictions. For example, the fact that in eCMR the similarity between the test context and the item is a factor of three different dimensions (temporal, semantic, and source contexts) led me to predict that an experimental manipulation that down-weights one of these factors will make a difference to which items are then recalled. Specifically, I am currently exploring whether the temporal context is less important (weighted down) when a long time passes between the test and the original experience. If correct, then the advantage of emotional over neutral items may be greater when participants recall them after a delay, compared to immediately.

In summary, eCMR explains enhanced emotional memory in mixed lists, why this effect disappears in pure lists, and why this effect could increase after a time delay. It is the only theory that can account for a pattern of empirical data called the emotional list-composition effect; but more importantly, it is the only theory of the cognitive mechanisms that underlie the effects of emotion on free recall, and the first formal model of emotional memory. To paraphrase the well-known quote from Box, while eCMR in its present form is probably wrong, I can only hope that it is useful.

To learn more about my work, please visit my website: https://www.psychol.cam.ac.uk/staff/dr-deborah-talmi.