Bilateral mutual gain control, beamforming, and Being There

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Abstract. In this presentation we will discuss our recent work on beamforming as a mechanism of selective attention, and its potential relationship to the enactive agenda. We propose that the enactive approach would benefit from extension to incorporate array sensing concepts and formalisms, and that array sensing expresses certain enactive core concepts in a practical way. Perception is radically embodied in that the physical morphology and dynamical distribution of the sensor array is fundamental. Attentional presence is extensive in physical spacetime in a quantifiable way, and is not reflected by any internal models. Beamforming with multimodal and dynamically adaptable array morphology is a state-of-the-art problem in communications technology. Thus the study of perceptual actions in animals as modes of beamforming may offer valuable mutual interaction with formal theory.

1 BILATERAL MUTUAL GAIN CONTROL AND BEAMFORMING

A. Bilateral mutual gain control and sensory attentional gating

The bilateral structure of the brain and body is aligned and integrated according to symmetric correspondence at many stages of sensory and motor processing. Mutual gain control (henceforth "MGC") is the most plausible general framework for bilateral sensory interaction, though many particulars exist at a more detailed level [4, 29, 10, 10, 28, 21]. From an aesthetic perspective, the "sweet spot" region of binaural synchrony is manipulated by sound engineers to deliver the most enjoyable and engaging listening experience [24, 2], suggestive of a more general multimodal link between bilateral gain control, arousal and "liking". Gain control is widely thought to mediate selective attention [8, 18, 1, 16, 17, 6, 20], and has been mechanistically linked to ascending projections from neuromodulatory hubs and the sympathetic nervous system [25, 1, 19], as well as feedforward mechanisms such as temporal correlation of presynaptic potentials [14].

B. Beamforming, orienting and motor attention

Beamforming is a technique for manipulating the spatial tuning of a sensor array [15]. The mathematical essence of beamforming is maximisation of constructive interference between the signals from an array of sensors. Integrating the signals from the array creates a set of preferred source locations for incoming signals. MGC is one possible integration function e.g. [11]. When the signals from all the sensors are temporally aligned, constructive interference is maximised and the input signal is faithfully reproduced. Otherwise, destructive interference damps the overall power of the signal. Adding differential delays to the sensor inputs, or physically turning the array, can rotate this "attentional beam" in space, so that sources at particular locations (e.g. a mobile phone) can be targeted, whilst noise from elsewhere is tuned out; a kind of technological "selective attention". Physically turning the array is analogous to the psychological concept of orienting or overt attention. Adding delays to "virtually" orient the array is analogous to "covert attention". Overt and covert attention are thought to be tightly linked [5, 3], though appear to be mediated by different cellular networks [7].

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2 BEAMFORMING AND BEING THERE

A. Attentional presence, embedded in spacetime

Beamforming projects an attentional field onto physical spacetime, which it is convenient to view in terms of "virtual sensors" extended into the environment. The visual horopter provides an example of one such virtual sensor, [22, 23], the auditory midline another [12]. The neural transforms (minimally, pointwise multiplication of the stereo signals) required are quite the opposite of internally representing space; (i) they purely collapse the spatial and modal extent of the array, (ii) they only discard and compress sensory information, (iii) they can be purely local and spatially uniform.

Spacetime is selectively inhabited externally by being selectively collapsed internally. Inhabited here refers to the tuning of the sensor array to particular locations and patterns of signal sources in the world, regardless of the signal content. This tuning is effected by the dynamic global posture of the sensor array at both the musculoskeletal (overt attention) and neural (covert attention) level. It is most convenient to characterise the agent's "presence" as an attentional field probabilistically co-extensive with the spatiotemporal lines of sight (or hearing etc) of its sensors. Indeed, there is no obvious alternative. It is not possible to properly characterise the form of the attentional field in terms of, for example, the retinal projection.

B. Context, content and consciousness

Hutto and Myin [9] argue for the possibility of consciousness without content. Beamforming provides a well worked formalism for defining attentional presence, regardless of content. Active maximisation of constructive interference (i.e. spatiotemporal resonance between sensor array and scene) corresponds fairly directly to Merleau-Ponty's notion of perception through establishment of "maximal grip" on the scene

[13]. The content of the signals may be discarded as soon as this quantity has been calculated. The array sensing approach is not anti-content, though. Indeed, it may play the role of framing and selecting content, and for this reason we associate beamforming with providing the spatiotemporal context of perception.

It is possible to make perceptual distinctions purely on the basis of beamforming. We have already shown that a number of "innate predispositions" regarding spatial-configural perception and social attention in newborns may be explained by bilateral MGC [27, 26]. Consider a sensory substitution device with one or more bilateral sensor pairs, whose signals are integrated by MGC. It outputs a one dimensional signal corresponding to the global level of constructive interference between all the bilateral sensor pairs. What perceptual distinctions are possible for humans and robots given some control of the array and this minimal feedback, and how are they made? Overall, we argue that array sensing provides a well specified and under-exploited paradigm to both explore and exemplify the potential of enactive perception.

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