The binding problem (bp)
Synchronized oscillations

- Roskies (‘99): bp - ‘‘one of the most puzzling and fascinating issues that the brain and cognitive sciences have ever faced’’
- Triesch and von der Malsburg (‘96): today’s key questions about brain function
- Treisman (‘96): a solution to bp may also throw light on the problem of the nature of conscious awareness” (Velik ‘10, p. 994)

- Spatial (location) and temporal binding
- Part binding (segregation of parts of an object from the background)
- Conscious and unconscious binding
- Perceptual (unifying aspects of percepts), visual binding (linking together color, form, motion, size, and location
- Cognitive (relating a concept to a percept): binding in language understanding; binding in reasoning
- Sensory-motor binding, cross-modal identification, and memory reconstruction

- Within a single modality or cross-modal; in action control or across perception and action
- Hierarchical binding ("the features of shape-defining boundaries (e.g. orientation, curvature, and closure) are bound to the surface-defining properties that carry them (e.g. luminance, color, texture, motion, and stereoscopic depth)" (Treisman '96)
- Feldman: feature binding (associating the visual features with objects), variable binding (natural language and other abstract thought), and the subjective unity of perception.

- Mind-body problem --- Mental representations really exist

Binding problem as a pseudo-problem:

- “If we consider entire cortical regions as a single network system acting as one resonating unit, then a vehicle for uniting disparate feature-bits would be unnecessary. Instead, the higher level statistical aggregate of firing neurons would unite sets of feature primitives.” (Hardcastle ‘96)
- O’Regan and Noe (‘01) “bp, in essence, a pseudo-problem’’

- Riesenhuber and Poggio (‘99): “bp - in the eye of the beholder, but is not necessarily a problem for all object recognition devices and perhaps may not be one for the brain.” (Velik ‘10)
- van der Velde: visual awareness cannot be solve “inside the brain” (LaRock ‘10)

- *Specialization* (differentiation) and *integration !*

I. Feature-Integration Theory (FIT)

- Anne Treisman. (Treisman and Gelade ‘80, Treisman ‘96, ‘99)
- (FIT) became not only the most influential theory of binding, but also the most influential theory of attention.” (Holcombe 09)
- Features of perceived object (color, size, motion, etc.) registered automatically + parallel at early stage
- Later - focus attention, certain features combined to form a single unitary object

- Conjunctions of various features necessitate focal attention that acts serially to each location

= “Window of attention” scans a “master map” of locations.

- Selecting features active in corresponding locations of various specialized feature maps + suppressing those in other locations to prevent erroneous binding.
- Selected features ---- “object token” - compared to stored representations to identify the object

- Binding - realized by common location (“common location tags”) of different features
- Argument - “illusory conjunctions”: without attention, conjunctions could be taken place accidentally creating illusory conjunctions since the features of unattended objects are “free floating” with respect to one another
- Theory has been changed during certain years
- B - focal attention and top-down processing

II. Synchrony /temporal coding theory (temporal b)

- von der Malsburg, by C. Legendy in ‘70, P. Milner in ‘74, and C. von der Malsburg in ‘81
- Bp - synchronous neuronal oscillations under different frequencies
- EEG or MEG - electrophysiological signals - at scalp level - “scalp signals reflect *synchronized* neural activity” or “rhythmic modulation of discharge activity (neuronal oscillations)” (Tallon-Baudry ‘09)

- Coupling of neurons through synchronization depend on adjusting phase relationship or frequency of cells from that neuronal group
- Inputs in “good phase” of the ongoing oscillation are selected, inputs in “bad phase” are suppressed (Moser et al. ‘10)
- Synchronization between different areas – through zero-phase lag between same frequent-oscillatory activities
- Zero-phase lag synchronization can occur over local brain areas or large distances

- *Delta* wave (less than 4 Hz) - slowest wave + greatest amplitude: deep sleep (unconscious) states.
- *Theta* wave (3.5 to 7.5 Hz Hz) – available: sleep states and meditation (short term memory)
- *Alpha* wave (7.5 to 13 Hz) – in relaxation moments (the eyes are close; open, alpha wave is attenuated)
- *Beta* wave (13-26 Hz) – irregular, low voltage: waking conscious states
- *Gamma* wave (26-70 Hz, centered around 40 Hz): conscious states (conscious perceptions and other cognitive states) and in REM dreams (rapid eyes movement sleep) (Low band (30-60 Hz) + high band (60-120 Hz))

- EEG results – only surface of waves
- Underneath, various kinds of interactions among waves (locked in synchrony with each other, phase-locked, transiently coordinated, cross-frequency coupling) with different ranges (recent discoveries indicate ranges from 0.01 to 1000 Hz) (Baars and Gage ‘10)
- *Keep in mind that brain rhythms are a moving target, as new evidence appears with remarkable rapidity.”* (Baars and Gage ‘10)

- Segmentation up to 90 Hz, for large distances is beta and gamma between 30-60 Hz
- Consciousness is associated with phase locking of gamma oscillations across widely distributed cortical areas
- Unconscious processes are associated with local gamma oscillations
- Firing rate (discharge rate) - for particular features, synchronization correlate these features (Singer ‘10)

- Integration of different neural patterns of activation that are correlated with particular mental functions
- Activity of neural patterns responsible for the mental (perceptual) feature, grouping all features of one (perceived) entity – synchronization
- Integration is correlated with the unity of consciousness/mind/subjectivity (the biding problem is the unity of perceptual scene/object)

What neural areas are active; what cognitive functions correlated with each band?

- In the past, each frequency band was associated with a cognitive function or state
- Actual associations: gamma range (plus alpha range) for the binding perceptual features, from theta to gamma frequency bands (but also alpha frequency) for various attentional tasks or for episodic memory encoding and retrieval, gamma and beta range for visual short-term memory (Tallon-Baudry ‘10)

- Cognitive functions associated with synchronization: binding (see below), attention (gamma and beta frequency bands) stimulus selection, and consciousness (Singer ‘10)
- Subdivisions of some frequency bands (for instance, gamma sub-bands) correspond to particular cognitive functions and vice-versa

- Interactions within large-scale cortical areas (communication) - produced by long-range synchronization of oscillatory signals
- Synchronization among distant neuronal areas - oscillations in the theta or beta frequency range;
- Synchronization among local groups of neurons is produced by gamma oscillations

- No strict correspondence between a frequency band and a cognitive process (Tallon-Baudry)
- Correlation between cognitive function-frequency band depend on two sets of features:

(1) Physiological needs (network's size and geometry, time, coding precision required, and metabolic costs for oscillations)

(2) Cognitive constraints (time, "chunks of processing", the number of cognitive function can be multiplexed)

Critics for the temporal coding hypothesis (Synchronization)

- Not for enduring trait of representation of an object (LaRock ‘10)
- Not for spatial structure necessary for binding the features (LaRock ‘07)
- Not for productivity in the case of binding (Frank van der Velde and Marc de Kamps ‘06)

- Very recent experiments on visual mechanism of monkeys - synchronization does not depend on bp but only on selectivity of finding the „border-ownership” of an object. (Yi Dong et al. ‘08)